HYDROCARBONS

MODULAR SYSTEM

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MODULAR SYSTEM

HYDROCARBONS

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PREFACE

Chemistry is an interesting and fundamental branch of science because it gives us the chance to explain the secrets of nature. What is water? What do we use in our cars as a fuel? What is aspirin? What are perfumes made of? Many of these kind of questions and their answers are all part of the world of chemistry. There is no industry that does not depend upon chemical substances: petroleum, pharmaceuticals, garment, aircraft, steel, electronics, agricultural, etc. This book helps everyone to understand nature. However, one does not need to be a chemist or scientist to understand the simplicity within the complexity around us.

The aim was to write a modern, up-to-date book where students and teachers can get concise information about the structure of substances. Sometimes reactions are given in detailed form, but, in all, excessive detail has been omitted.

The book is designed to introduce basic knowledge about chemical bonds. Chemists work everyday to produce new compounds to make our lives easier with the help of this basic knowledge. In the design, emphasis has been placed upon making the book student friendly. Throughout the books, colorful tables, important reactions, funny cartoons, interesting extras and reading passages are used to help explain ideas .This book will also show you how chemical bonds are useful to us in everyday life. We hope, after studying this book, you will find chemistry in every part of your life.

The authors would like to thank Orhan Keskin, Ali Çavdar and Ramazan Şahin for their support and encouragement throughout the development of this book.

We would also like to thank Tekin Çorbalı, Mustafa Yılmaz and Okan Çeliker for their thoughtful criticisms and helpful suggestions to the manuscript which have been of such great value in developing the book.

Many people have assisted us in writing these books. We wish to gratefully acknowledge the contributions of Osman Yıldırım, Sani Demiri and Tolga Başbuğ for their reviews and suggestions.

We are particularly grateful to our spouses and children for their patience during the writing of the book.

The Authors

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HYDROCARBONS

INTRODUCTION

Everybody might know "C" as the symbol of carbon. However, it is not only a symbol but a special key for about 20.000.000 known compounds!

Organic chemistry, carbon chemistry, is a huge branch of the chemistry tree and indeed, it can be said that we live in an Organic Chemistry Age in the 21st century.

The substances studied in organic chemistry are called organic compounds and they are vital for all living things on this planet.

Petroleum, natural gas and coal are the main sources of organic compounds. These sources are formed by the decaying over time of living organisms.

Organic chemistry is the chemistry of paints, plastics, drugs, dyes, paper, ink, gasoline and rubbers. Most of the medicines that we use are also organic. Almost all of our food and many food additives are organic and all polymers we use in our life such as polyethylene, polypropylene, teflon, polystyrene etc. are organic.

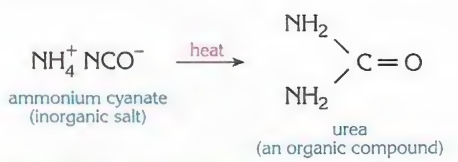
It can be said that organic chemistry is related with every part of our lives and understanding organic compounds has led to a complete change in our lives.

READING — A SHORT HISTORY OF ORGANIC CHEMISTRY

For over hundreds of years chemists have classified compounds as coming either from minerals (non-living origin) or from plants and animals (living origin). In the 9th century an Arabic alchemist Abu Bakr Er-Razi (865-925) first indicated this classification. Over a thousand years later, this classification is still used.

At the beginning of the 19th century the Swedish chemist Jacob Berzelius (1779-1848) first used the term "organic". He thought that organic compounds could only be formed by the "vital power" which exists in living organisms. Because of this, it was thought that they could only be extracted from living organisms.

That idea was completely changed by the German chemist Friedrich Wöhler (1800-1882). He synthesized urea, the end product of nitrogen excretion in mammals, and became the first scientist to synthesize an organic compound from an inorganic compound.



Some other important milestones in the history of organic chemistry are:

- *In 1784, Lavoisier proved that organic compounds include carbon, hydrogen and oxygen.*
- *In 1853, the English chemist Edward Frankland used the term valency (latin word valentia-force).*
- *In 1857 two German scientists Kekulé and Adolf Korbe explained the tetravalency of carbon.*
- *Between 1858-1861, August Kekulé, Archibald Scott Couper and Alexander M. Butlerov independently established one of the fundamental theories in organic chemistry: "The Structural Theory of Organic Compounds".*
- *In 1874 structural formulae were proposed by van't Hoff and Le Bel to represent organic compounds eg. methane, CH_4. Carbon in the center and hydrogens at the corners.*
- *In 1916 the first explanation of chemical bonding was proposed by G. Lewis and W. Kössel. Ionic and covalent bonding was explained.*

1. DIFFERENCES BETWEEN ORGANIC AND INORGANIC COMPOUNDS

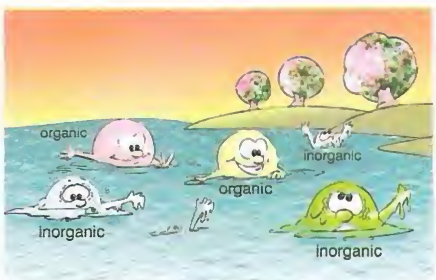
Organic compounds are produced by living things but inorganic compounds are produced by non-living natural processes and by human intervention in the laboratory. This was the most frequent description of "organic" until Wöhler's (1828) synthesis of urea (an organic compound) from ammonium cyanate (an inorganic salt). Now many organic substances are being synthesized by scientists. So being 'natural' does not distinguish organic compounds from inorganic ones.

ORGANIC	INORGANIC
1. A huge number of compounds due to the bonding ability of the carbon atom. There are about 20.000.000 known organic compounds.	1. A smaller number of compounds. There are about 400.000 compounds.
2. Compounds include a few different elements only (carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorus and the halogens).	2. Compounds may include any from about 100 different elements.
3. Compounds have covalent bonds and may be huge molecules with long chains.	3. Compounds have ionic bonds and simple, small ratios of elements.
4. Often in liquid or gaseous state because of the weak intermolecular forces between the molecules.	4. Most of them exist in the solid state. They have high melting and boiling points.
5. Reactions are very slow, catalysts are often needed.	5. Reactions are fast and take place easily.
6. Soluble in organic solvents but not in water.	6. Soluble in water and conduct electricity well in solution.
7. Have specific colors and odors.	7. Generally colorless and odorless.

Table 1: *Differences between organic and inorganic compounds*

2. DETECTION OF SOME ELEMENTS IN ORGANIC COMPOUNDS

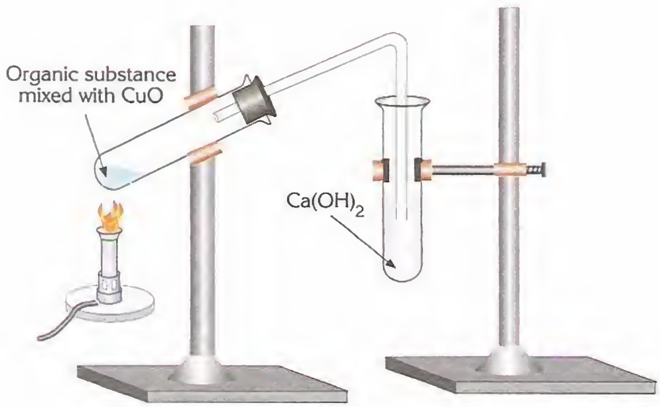
Organic compounds may consist of carbon, hydrogen, oxygen, nitrogen, the halogens, sulfur and phosphorus. The most common elements in organic compounds are carbon, hydrogen, oxygen and nitrogen. These four elements form 95% of the human body.



Organic compounds are generally not soluble in water.

2.1. DETECTION OF HYDROGEN AND CARBON

In a test tube, an organic substance such as sugar is mixed with the same amount of copper (II) oxide, CuO. After closing the test tube with a stopper, and passing a delivery tube into another test tube containing lime water, $Ca(OH)_2$, the mixture is heated.



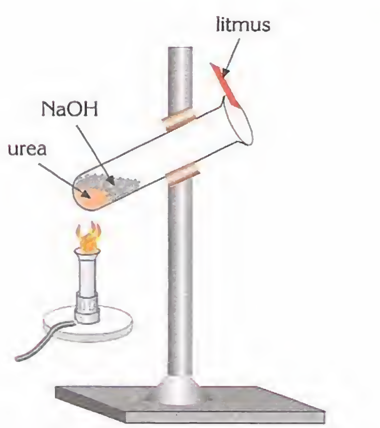
Detection of carbon and hydrogen in organic substances

$$C \text{ (from the organic compound)} + 2CuO \longrightarrow CO_2 + 2Cu$$

$$2H \text{ (from the organic compound)} + CuO \longrightarrow H_2O + Cu$$

Water droplets indicate that the organic substance contains hydrogen. On the other hand, if carbon is present, carbon dioxide is formed and this turns the limewater cloudy, due to the formation of calcium carbonate

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3\downarrow + H_2O$$



Detection of nitrogen in organic substances

2.2. DETECTION OF NITROGEN

In a large test tube, urea and NaOH are mixed and heated. During heating, ammonia is produced and can be identified by its sharp odor or by using litmus paper which turns blue after being put into the opening of the test tube.

$$(NH_2)_2C{=}O + 2NaOH \longrightarrow Na_2CO_3 + 2NH_3$$

Formation of ammonia shows that the organic compound contains nitrogen.

3. FORMULA CONCEPT IN ORGANIC CHEMISTRY

We know that a chemical formula shows the numbers, kinds and proportions of atoms in a compound.

When we look at a chemical formula of an inorganic compound, the number of atoms and the types of bonding can easily be understood. In inorganic compounds there are no other compounds with the same formula. NaCl represents sodium chloride and there is no other compound which is shown by this formula.

In organic chemistry though, many different compounds may have the same number and kind of atoms. For example, C_5H_{12} may be the symbol of three different compounds, and there are 14 different compounds which have the $C_5H_{12}O$ formula.

Although the numbers of atoms are the same, the physical and chemical properties of these compounds differ. For this reason, it is necessary to show the structures of compounds in organic chemistry.

There are three ways to write a formula in organic chemistry;

CH	C_2H_2	$H-C\equiv C-H$
emprical formula	molecular formula	structural formula

Empirical Formula

This indicates the type and ratio of atoms in a compound. It doesn't necessarily show the correct number of atoms and so the exact structure of a compound may not be understood when using this formula.

For example; CH may represent either C_2H_2 or C_6H_6

Molecular Formula

The molecular formula shows the actual number of atoms in a compound.

"n" is an integer; 1, 2, 3......

For $(CH_2)_n$ if n=2 then the molecular formula is C_2H_4; if it is 3 the molecular formula will be C_3H_6 .

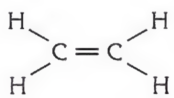
When we know the empirical formula and atomic weight of a compound the molecular formula can be determined. For example;

if	$M_{(CH_2)_n} = 28$ g/mol	if	$(CH_2)_n = 42$ g/mol
then	$(12 + 2\cdot 1)n = 28$	then	$(12 + 2\cdot 1)n = 42$
	$14n = 28$		$14n = 42$
	$n = 2$		$n = 3$
	C_2H_4		C_3H_6

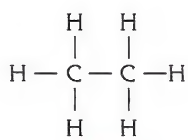
Structural Formula

Although a molecular formula shows the number of atoms in a compound, it does not show the type of bonding between atoms. We can show how atoms are bonded to each other by using structural formula.

Such as;

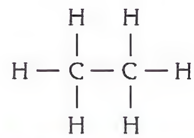


ethene



ethane

If there is more than one group that is bonded to the same central atom, the groups may be written in parentheses and number of the groups written outside the parentheses as a subscript.

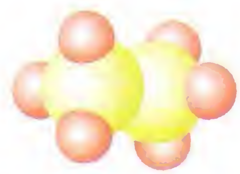


a. Dash representation

$CH_3 - CH_3$

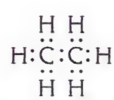
(CH_3CH_3)

b. Condensed formula



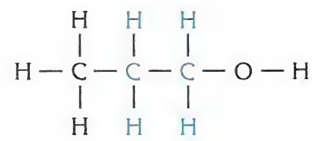
c. Space filling model

d. Ball and stick model

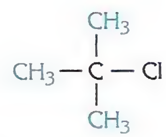


e. Lewis structure

Such as;

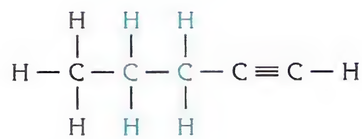


$CH_3(CH_2)_2OH$

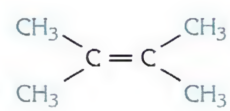


$(CH_3)_3CCl$

$CH_3CH_2CH_2CH_2CH_2CH_3$ $\quad$ $CH_3(CH_2)_4CH_3$



$CH_3(CH_2)_2C \equiv CH$



$(CH_3)_2C = C(CH_3)_2$

Example **1**

0.3 grams of an organic compound contains C, H and O atoms. If the masses of C and H are 0.12 g and 0.02 g respectively, what is the empirical formula of this compound? (O : 16 g/mol, C : 12 g/mol, H : 1 g/mol)

Solution

First, let's find the mass of oxygen in the organic compound.
We know that

$m_C + m_H + m_O = 0.30$ g

$0.12 \text{ g} + 0.02 \text{ g} + m_O = 0.30 \text{ g} \qquad m_O = 0.16 \text{ g}$

Now we find the number of moles of each atom.

for C; $\quad$ 0.12 g/12 g/mol = 0.01 mol

for H; $\quad$ 0.02 g/1 g/mol = 0.02 mol

for O; $\quad$ 0.16 g/16 g/mol = 0.01 mol

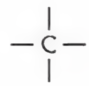
The mole ratio of elements in the compound is $C_{0.01}\,H_{0.02}\,O_{0.01}$

So the empirical formula is CH_2O

4. STRUCTURAL THEORY OF ORGANIC COMPOUNDS

An understanding of how elements are connected together in organic compounds can be gained from the structural theory of organic compounds. This theory is a result of the independent studies of Butlerov, Kekulé and Couper between 1857-1861. Briefly, the theory explains that:

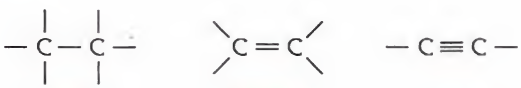
1. All atoms form a certain number of bonds in organic compounds. This can be explained by the "valency concept".

   eg. carbon has a valency of four, (it is tetravalent): 

   oxygen has a valency of two, it is divalent: —O—

   hydrogen and halogens have a valency of one, they are monovalent: H–, X–

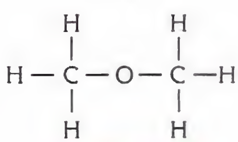
2. A carbon atom can form single, double or triple bonds with other carbon atoms.



single double triple

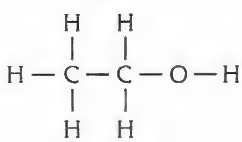
3. Two compounds with the same molecular formula may differ in the connection of their elements. Properties of organic compounds are not only related with the number and type of elements found in them but also with the order of bonding of the elements to each other.

C_2H_6O

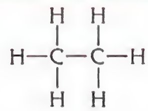
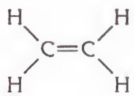
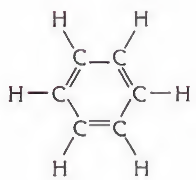
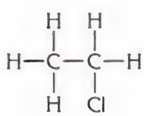
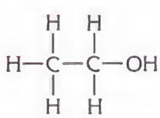
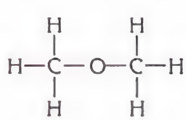
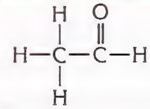
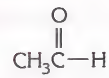
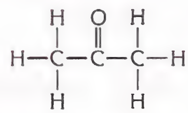
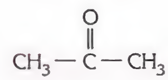
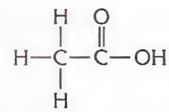
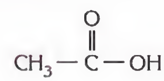
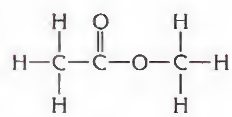
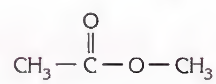
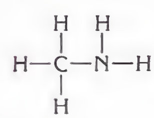
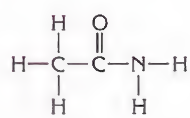
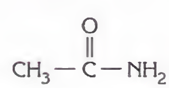


dimethyl ether

C_2H_6O



ethyl alcohol

Family	Specific example	Name	General Formula
Alkane C_2H_6	 CH_3CH_3	Ethane	R—H
Alkene C_2H_4	 CH_2CH_2	Ethylene	$RCH{=}CH_2$ $RCH{=}CHR$ $R'C{=}CHR$ $R'C{=}CR'$
Alkyne C_2H_2	$H{-}C{\equiv}C{-}H$ HCCH	Acetylene	$RC{\equiv}CH$ $RC{\equiv}CR$
Arene C_6H_6		Benzene	ArH
Haloalkane C_2H_5Cl	 CH_3CH_2Cl	Ethyl chloride	RX
Alcohol C_2H_5OH	 $CH_3{-}CH_2{-}OH$	Ethyl alcohol	ROH
Ether C_2H_6O	 $CH_3{-}O{-}CH_3$	Dimethyl ether	ROR
Aldehyde CH_3CHO	 	Acetaldehyde	$R\overset{\overset{O}{\Vert}}{C}H$
Ketone CH_3COCH_3	 	Acetone	$R\overset{\overset{O}{\Vert}}{C}R$
Carboxylic Acid CH_3COOH	 	Acetic acid	$R\overset{\overset{O}{\Vert}}{C}OH$
Ester CH_3COOCH_3	 	Methyl acetate	$R\overset{\overset{O}{\Vert}}{C}OR$
Amine CH_3NH_2	 $CH_3{-}NH_2$	Methyl amine	RNH_2 $R'NH$ $R''N$
Amide CH_3CONH_2	 	Acetamide	$R\overset{\overset{O}{\Vert}}{C}NH_2$ $R\overset{\overset{O}{\Vert}}{C}NHR'$ $R\overset{\overset{O}{\Vert}}{C}NR'R''$

* R : Alkyl radical, Ar : Aryl radical, X : Halogens)

Table 1 : *Important families of organic compounds.*

SUPPLEMENTARY QUESTIONS

1. What are the differences between organic and inorganic compounds?

2. Give five examples of organic and inorganic substances that you use at home.

3. What are the most common elements found in organic compounds?

4. What is the most important source of organic compounds?

5. Which properties of carbon make it unique?

6. Draw the dash formulae, condensed formulae and Lewis structures of;

   a. C_2H_6 b. C_3H_8 c. C_2H_4 d. C_2H_2

7. How can we prove the presence of carbon and hydrogen in organic compounds?

8. Suggest a method to prove the presence of nitrogen in an organic compound.

9. What is the difference between an empirical and a molecular formula? Give an example.

10. 1/7'th of an organic compound containing carbon and hydrogen is hydrogen by mass. Find its empirical formula.

11. An organic compound was found to contain 10% hydrogen and 90% carbon by mass. Find its empirical formula.

12. Find the empirical formula of the organic compound of which 3 g contains 0.6 g of hydrogen and 2.4 g carbon.

13. Acetic acid, CH_3COOH, constitutes about 5% of vinegar. Find the mass percentages of all the elements in acetic acid. (C : 12, O : 16, H : 1)

14. The empirical formula of an organic compound is CH_2O. Find its molecular formula if its molar mass is 180 g/mol.

15. An organic compound whose molar mass is 88 g/mol contains 55% C, 36% O and 9% H by mass. Find its molecular formula.

16. An organic compound contains only 1.5 g hydrogen and 9 g carbon by mass. Find its molecular formula if its molar mass is 210 g/mol.

MULTIPLE CHOICE QUESTIONS

1. All of the following are organic except:

A) Gasoline B) Paper C) Plastics
D) Water E) Human body

2. Which one of the following elements is present in the smallest amount in the human body?

A) Carbon B) Silicon C) Hydrogen
D) Oxygen E) Nitrogen

3. I. Air
II. Petroleum
III. Natural gas

Which of the above is/are a source of organic compounds?

A) I only B) II only C) III only
D) I and II E) II and III

4. Which of the following is not valid for organic compounds?

A) The main element is carbon.
B) They are soluble in water.
C) They are often liquid or gas at STP.
D) Their reactions are usually slow.
E) Their molecules may contain oxygen and hydrogen.

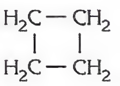
5. I. To detect carbon, CuO is used.
II. To detect nitrogen, NaOH is used.
III. Hydrogen in organic compounds forms water when heated with CuO.

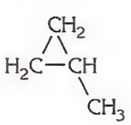
Which of the given statements is/are correct?

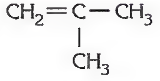
A) I only B) II only C) I and II
D) II and III E) I, II and III

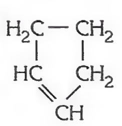
6. All of the following have the same empirical formula except:

A) $CH_3-CH=CH-CH_3$

B) 

C) 

D) 

E) 

7. Which is not correct for $CH_3 — O — CH_3$ and $CH_3 — CH_2 — OH$?

A) They have the same molecular formula.

B) They have the same molar mass.

C) Their percentage composition are identical.

D) They have the same empirical formula.

E) They are the same compounds.

8. I. Molar mass

II. Types of the atoms

III. Numbers of atoms in a molecule

Which of the above can not be determined by the empirical formula of a compound?

A) I only B) II only C) III only

D) I and III E) II and III

9. Which of the following is incorrect for carbon?

A) It is tetravalent.

B) It can form single, double and triple bonds.

C) It can form stable long chains.

D) It is very electronegative.

E) It can form cyclic structures.

10. An organic compound whose molar mass is 60 g/mol contains 40% carbon, 53.3% oxygen and 6.7% hydrogen. What is the molecular formula of this compound?

A) CH_2O B) C_3H_8O C) C_4H_{12}

D) $C_2H_4O_2$ E) H_2CO_3

DOUBLE PUZZLE

These words have been jumbled up (There are no letters missing). Luckily clues have been left. Put the correct spelling in the Answer Grid. Transfer the numbered letters to the reference check and use this to fill in the SECRET MESSAGE.

ANSWER GRID

10			18		

4		2		15		

			14			6		

			17		23				3

25		11			1			

26			25					

24			5

CLUES

Organic chemistry is also known as ___________ chemistry.

___________ compounds are soluble in organic solvents but insoluble in water.

Organic reactions are very slow, ___________ are often needed to increase the reaction rate.

We can show how atoms are bonded to each other by using ___________ formula.

___________ formula is the simplest formula that shows the relative numbers of different kinds of atoms in a molecule.

___________ formula shows the number of atoms in a compound.

It is the bonding capacity of the carbon atom.

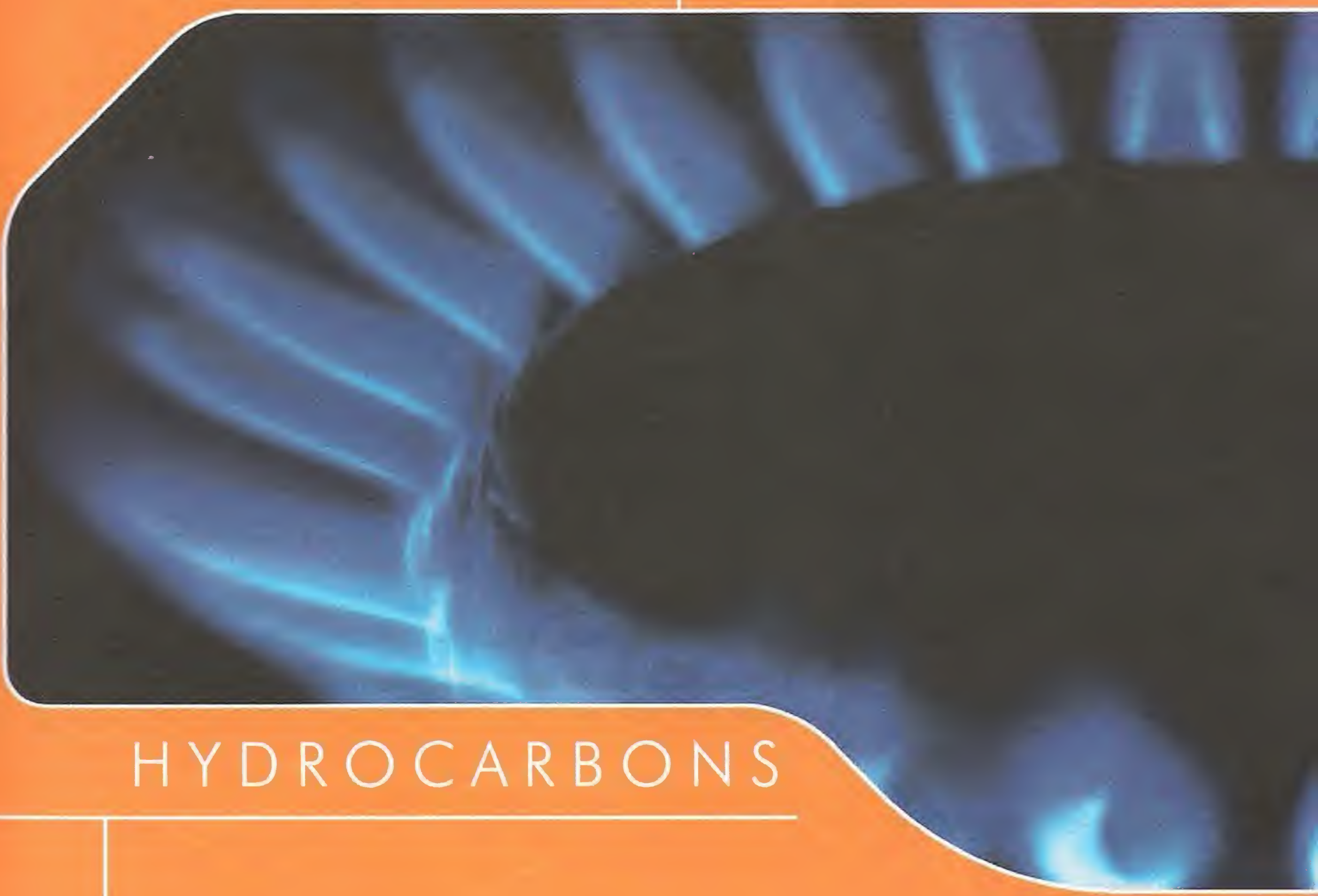
REFERENCE CHECK

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
			19				12														16	13			

SECRET MESSAGE

11	25	23	5	4	3	25	17	26		14	15	19		10	4	14	3		14	5	25		23	13	4	
3	14	5	2	25		5	25	6	25	5	16	4	1	5	6		4	24		4	5	2	14	15	1	10
26	14	23	25	5	1	14	3		24	5	4	26		13	12	1	10	12		6	1	26	11	3	25	
4	5	2	14	15	1	10		10	4	26	11	4	17	15	19	6		10	14	15		18	25			
									4	18	23	14	1	15	25	19										

ALKANES



HYDROCARBONS

Candle wax contains saturated hydrocarbons.

INTRODUCTION

Hydrocarbons, as the name suggests, are organic compounds containing carbon and hydrogen. They are extracted from petroleum, natural gas and coal. For this reason organic chemistry is very much related to the petroleum industry.

Hydrocarbons can be split into two main categories **aliphatic** and **aromatic**.

Aliphatic hydrocarbons have straight or branched structures. They are classified as saturated or unsaturated according to the type of bonding in their structures.

Aromatic hydrocarbons contain the benzene ring structure. So hydrocarbons may be classified as follows;

HYDROCARBONS

- Aliphatic Hydrocarbons
  - Saturated
    1. Alkanes (Paraffins)
  - Unsaturated
    1. Alkenes (Olefins)
    2. Alkynes
- Aromatic Hydrocarbons

1. ALKANES

Latin Numbers	
1	Mono
2	Di
3	Tri
4	Tetra
5	Penta
6	Hexa
7	Hepta
8	Octa
9	Nona
10	Deca

Table 1: *Some Latin numbers*

Alkanes are very common organic compounds. In our daily lives, we meet them in most every place, for example, gasoline, natural gas and candle wax all consist of alkanes.

In alkanes or saturated hydrocarbons, each carbon atom forms four covalent bonds. These bonds are C — C and C — H sigma bonds. Sigma bonds are very strong, so for this reason, alkanes are also known as paraffins which means "inert".

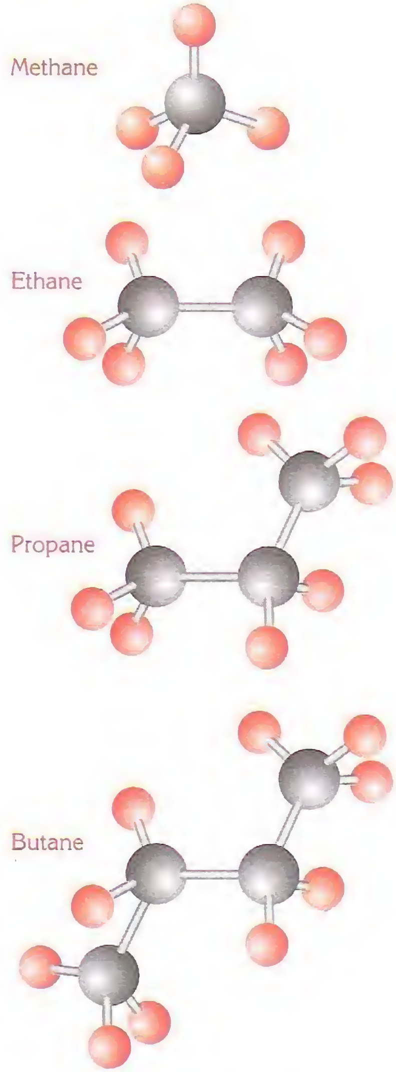
The general formula of the alkanes is C_nH_{2n+2} , where n is an integer and indicates the number of carbon atoms.

The first four members of the alkanes have common names: methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}). After the fourth carbon, Latin numbers are used to name alkanes. For example: Five is penta in Latin.

C_5H_{12} is named penta + ane = pentane.

Name	Number of Carbon Atoms	Molecular Formula	Condensed Formula
Methane	1	CH_4	CH_4
Ethane	2	C_2H_6	CH_3CH_3
Propane	3	C_3H_8	$CH_3CH_2CH_3$
Butane	4	C_4H_{10}	$CH_3(CH_2)_2CH_3$
Pentane	5	C_5H_{12}	$CH_3(CH_2)_3CH_3$
Hexane	6	C_6H_{14}	$CH_3(CH_2)_4CH_3$
Heptane	7	C_7H_{16}	$CH_3(CH_2)_5CH_3$
Octane	8	C_8H_{18}	$CH_3(CH_2)_6CH_3$
Nonane	9	C_9H_{20}	$CH_3(CH_2)_7CH_3$
Decane	10	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$
Undecane	11	$C_{11}H_{24}$	$CH_3(CH_2)_9CH_3$
Dodecane	12	$C_{12}H_{26}$	$CH_3(CH_2)_{10}CH_3$
Tridecane	13	$C_{13}H_{28}$	$CH_3(CH_2)_{11}CH_3$
Eicosane	20	$C_{20}H_{42}$	$CH_3(CH_2)_{18}CH_3$
Triacontane	30	$C_{30}H_{62}$	$CH_3(CH_2)_{28}CH_3$
Tetracontane	40	$C_{40}H_{82}$	$CH_3(CH_2)_{38}CH_3$
Pentacontane	50	$C_{50}H_{102}$	$CH_3(CH_2)_{48}CH_3$
Hexacontane	60	$C_{60}H_{122}$	$CH_3(CH_2)_{58}CH_3$
Heptacontane	70	$C_{70}H_{142}$	$CH_3(CH_2)_{68}CH_3$
Octacontane	80	$C_{80}H_{162}$	$CH_3(CH_2)_{78}CH_3$
Nonacontane	90	$C_{90}H_{182}$	$CH_3(CH_2)_{88}CH_3$
Hectane	100	$C_{100}H_{202}$	$CH_3(CH_2)_{98}CH_3$

Table 2 : *The alkanes*



Molecular models of the first four alkanes

In table 2, some alkanes are given together with the number of carbon atoms in the molecule. There is a ($-CH_2-$) difference between members of consecutive alkanes. For example, between C_3H_6 and C_4H_{10} the atoms increase by 1C and 2H ($-CH_2-$). A series of compounds in which the members are built up in this way is referred to as a ***homologous series***. The alkanes are a homologous series. Compounds that form an homologous series show similar properties.

Straight chain alkanes take n- in the front of name, which means "normal" and shows the alkane is unbranched.

Homologous Series:

As is seen in table 2 consecutive alkanes differ from each other by a methylene ($-CH_2-$) group.

A series of compounds in which the members are built up in this way is referred to as a "homologous series".

In branched alkanes, if there is one methyl ($-\dot{C}H_3$) group on the second carbon, the "iso" prefix is added to the front of the parent name.
Alternatively, if there are two methyl groups attached to the second carbon atom the "neo" prefix is added to the parent name.

Molecular Formula	Normal Alkane	Isoalkane	Neoalkane
C_4H_{10} butane	$CH_3-CH_2-CH_2-CH_3$ n–butane	$CH_3-CH(CH_3)-CH_3$ isobutane	—
C_5H_{12} pentane	$CH_3-CH_2-CH_2-CH_2-CH_3$ n–pentane	$CH_3-CH(CH_3)-CH_2-CH_3$ isopentane	$CH_3-C(CH_3)_2-CH_3$ neopentane
C_6H_{14} hexane	$CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$ n–hexane	$CH_3-CH(CH_3)-CH_2-CH_2-CH_3$ isohexane	$CH_3-C(CH_3)_2-CH_2-CH_3$ neohexane

Table 3 : *Structures of normal, iso and neo alkanes.*

Example 1

What is the molecular formula of a saturated hydrocarbon if 0.05 moles of the compound has a mass of 3.6 grams? (C:12, H:1)

Solution

Let us find the molecular weight of the alkane.

If 0.05 mole weighs 3.6 g
1 mole weighs x g

$$x = \frac{3.6\text{ g} \cdot 1\text{ mol}}{0.05\text{ mol}} = 72\text{ g/mol}$$

We know that general formula of alkanes is C_nH_{2n+2} So,

$C_nH_{2n+2} = 72$

$12n + 1 \cdot (2n + 2) = 72$

$14n + 2 = 72$ $\quad n = 5$

So the molecular formula of the alkane is C_5H_{12}

Example 2

The mass ratio between hydrogen and carbon in an alkane is 7/36. What is the molecular formula of this hydrocarbon?

(C:12, H:1)

Solution

The general formula of alkanes is C_nH_{2n+2} .

So in an alkane the mass of carbon is 12n grams and the mass of hydrogen is 2n+2 grams.

$$\frac{2n+2}{12n} = \frac{7}{36}$$

$$72n + 72 = 84n$$

$$72 = 12n$$

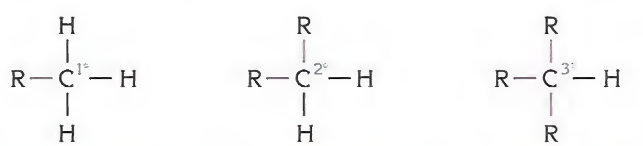
$$n = 6$$

The molecular formula of the alkane is C_6H_{14}

2. ALKYL GROUPS

If one hydrogen is removed from an alkane, an alkyl group is formed. The general formula for an alkyl group is C_nH_{2n+1} . Instead of the –ane suffix in alkanes, "–yl" is used for naming alkyl groups. They can also be shown by "R". R represents "radical".

A carbon atom in an alkane can be named as primary, secondary or tertiary according to the number of other carbon atoms to which it is attached.

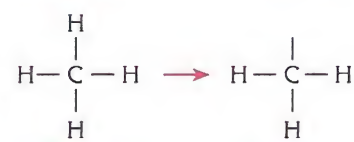


1° primary carbon   2° secondary carbon   3° tertiary carbon

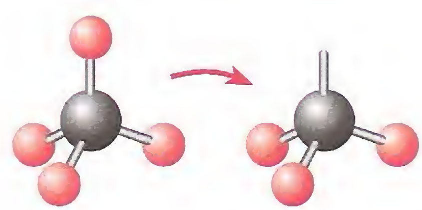
Alkyl groups can be defined as primary, secondary or tertiary depending upon their structures.

$C_nH_{2n+2} \longrightarrow C_nH_{2n+1}$

Alkane   Alkyl



Methane   Methyl



Methane (CH_4)   Methyl ($-CH_3$)

Methane and the methyl group.

Alkane	Number of Carbon atoms	Structure	Alkyl	Structure
Methane	1	CH_4	Methyl	$-CH_3$
Ethane	2	CH_3-CH_3	Ethyl	$-CH_2-CH_3$
Propane	3	$CH_3-CH_2-CH_3$	n–propyl	$-CH_2-CH_2-CH_3$
			Isopropyl	$-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-CH_3$
Butane	4	$CH_3-CH_2-CH_2-CH_3$	n–butyl	$-CH_2-CH_2-CH_2-CH_3$
			sec–butyl	$-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-CH_2-CH_3$
			Isobutyl	$-CH_2-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-CH_3$
			tert–butyl	$-\overset{\displaystyle CH_3}{\overset{\vert}{\underset{\displaystyle CH_3}{\underset{\vert}{C}}}}-CH_3$

Table 4 : *The first four alkanes and their alkyl groups.*

3. NOMENCLATURE OF ALKANES

Alkanes can be named in two ways, with a common name or an IUPAC name.

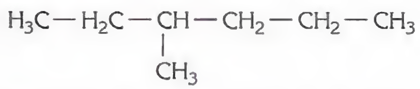
IUPAC : The International Union of Pure and Applied Chemistry.

Methane, ethane, propane, n–butane, n–pentane, isopentane, etc. are common names that have little systematic basis and cause confusion in nomenclature. To prevent this, IUPAC developed a standard for naming organic compounds. According to the IUPAC system, there is only one name for a compound.

To name the alkanes according to the IUPAC system the following rules can be used.

Rule 1.

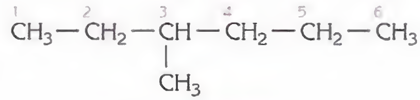
Determine the chain with the longest continuous number of carbon atoms. This gives the starting name (often called the parent name) of the alkane.



There are six carbon atoms in the longest chain in the example. So the parent name of the compound is hexane.

Rule 2.

Number the carbon atoms in the longest chain, starting at the end closest to the branching.

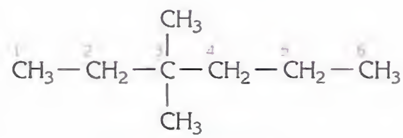


3 - methylhexane

In nomenclature, to separate a number from a word use a dash (–); to separate numbers from one another use a comma.

Rule 3.

If there is more than one identical substituent the number of substituent is indicated by using prefixes –di, –tri, –tetra and so on.

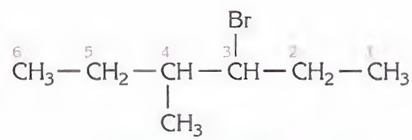


3,3 - dimethylhexane

Some important substituents other than alkyl groups are the halogens, —F (fluoro), —Cl (chloro), —Br (bromo), —I (iodo), hydroxyl (—OH), nitro (—NO_2) and amino (—NH_2) groups.

Rule 4.

When two or more different substituents are bonded to the carbon chain, they are ordered alphabetically.



3 - bromo - 4 - methylhexane

EXTRA

IUPAC

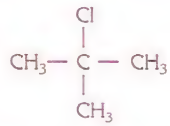
At the end of the 19th century, many organic compounds had already been discovered. As a result, the need for an international naming system increased. In 1892, chemists took some initial decisions in Switzerland, Geneva.

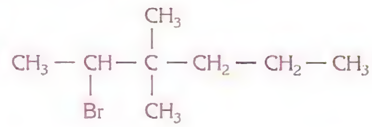
Those decisions were revised and improved by a meeting held in Liege, Belgium in 1930. These decisions were applied under the name of "Liege Rules". After World War II, the formal system of naming of organic substances was proposed by the International Union of Pure and Applied Chemistry, IUPAC. All of these standards were published in 1979 and used internationally.

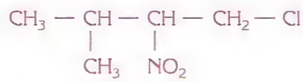
Consequently, the naming of organic compounds is now described by a standard system.

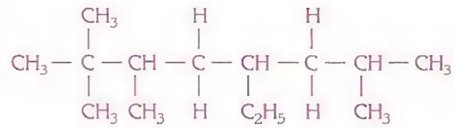
Example 3

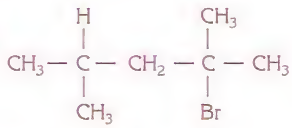
Give the IUPAC names for each of the following compounds.

a. 

b. 

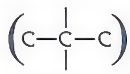
c. 

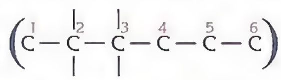
d. 

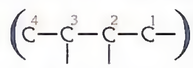
e. 

Solution

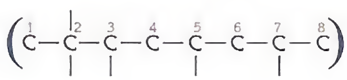
a. The longest carbon chain, has 3 carbons. So the parent name of the compound is propane.

In the  structure $-CH_3$ and $-Cl$ are attached to the second carbon; in alphabetical order, chlorine comes before methyl.
So the name of the compound is *2 – chloro – 2 – methylpropane.*

b. The longest carbon chain contains 6 carbon atoms. So the compound is based on hexane  $-Br$ is attached to the second carbon and two methyl groups ($-CH_3$) are attached to the third carbon.
So the name is *2 – bromo – 3,3 – dimethylhexane.*

c. The longest carbon chain  has 4 carbon atoms.

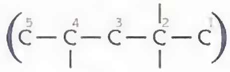
The parent name is butane. On the first carbon $-Cl$, on second carbon $-NO_2$ and on the third $-CH_3$ substituents are attached.
So the name is *1 – chloro – 3 – methyl – 2 – nitrobutane.*

d. The longest chain  has 8 carbons.

The parent name is octane.

There is one $-CH_3$ on the 7th carbon and the 3rd carbon; two $-CH_3$ groups on the 2nd carbon and a $-C_2H_5$ group on 5th carbon.

So the name is *5 – ethyl – 2, 2, 3, 7 – tetramethyloctane.*

e. The longest chain  has five carbon atoms.

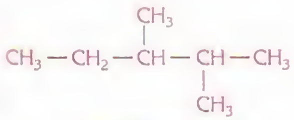
The parent name is pentane. If it is numbered from right to left, there is one $-CH_3$ group and one bromine on the 2^{nd} carbon and one $-CH_3$ group on the 4^{th} carbon atom.

So the name is *2 – bromo – 2,4 – dimethylpentane.*

Example 4

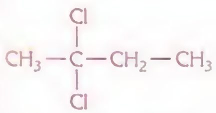
Compare the names with the structures. Which compounds are labelled correctly?

a.



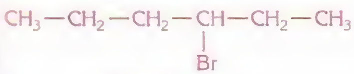
3,4–dimethylpentane

b.



2,2–dichlorobutane

c.



4–bromohexane

Solution

a. The longest chain has 5 carbon atoms, therefore it is based on pentane. The carbon atoms to which the methyl groups are attached to must be numbered with the smallest numbers. So the numbering should start from the right. Hence, the name of the compound should be 2,3 – dimethylpentane; 3,4 – dimethylpentane is not correct.

b. The longest chain has 4 carbons, it is based on butane. The numbering should start from left because the branching starts at the left end. So the name of the compound is 2,2 – dichlorobutane. The given name is correct.

c. The longest chain has 6 carbons, it is based on hexane. If the numbering starts from the right, –Br is attached to the 3rd carbon. The name isn't 4 – bromohexane but 3 – bromohexane.

Example 5

In the given hydrocarbon a methyl group is represented by R, an ethyl group by R′ and a propyl by R″. What is the name of the following compound?

$$\begin{array}{c} \qquad\qquad R \\ \qquad\qquad | \\ R - CH_2 - C - R'' \\ \qquad\qquad | \\ \qquad\qquad R' \end{array}$$

Solution

The structure of compound must be as follows;

$$\begin{array}{c} \qquad\qquad\quad CH_3 \\ \qquad\qquad\quad | \\ CH_3 - CH_2 - C - C_3H_7 \\ \qquad\qquad\quad | \\ \qquad\qquad\quad C_2H_5 \end{array} \Rightarrow \begin{array}{c} \qquad\qquad\qquad CH_3 \\ \qquad\qquad\qquad | \\ \overset{1}{C}H_3 - \overset{2}{C}H_2 - \overset{3}{C} - \overset{4}{C}H_2 - \overset{5}{C}H_2 - \overset{6}{C}H_3 \\ \qquad\qquad\qquad | \\ \qquad\qquad\qquad C_2H_5 \end{array}$$

The longest chain of carbon atoms is six. If the carbon atoms are numbered from left to right, there is one methyl and one ethyl group on the third carbon atom. The name of the compound will be 3 – ethyl – 3 – methylhexane.

4. ISOMERISM IN ALKANES

Isomers are different compounds that have the same molecular formula. The atoms are just arranged in a different order.

The first three members of the alkanes (methane, ethane and propane) don't have isomers. Butane, however, does have isomers and these are shown below. The first compound (1) has a longest chain of four carbons and is called n – butane but the second compound (2) has a longest chain of three carbons. But both compounds have the same molecular formula C_4H_{10}.

$$CH_3 - CH_2 - CH_2 - CH_3 \quad \text{or} \quad \begin{array}{c} CH_3 \\ | \\ CH_3 - CH - CH_3 \end{array}$$

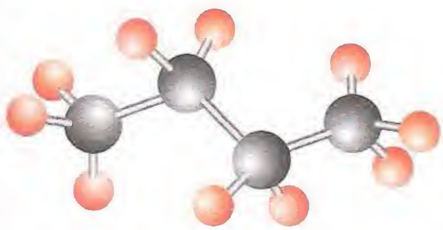
(1) n – butane

(2) 2 – methylpropane (isobutane)

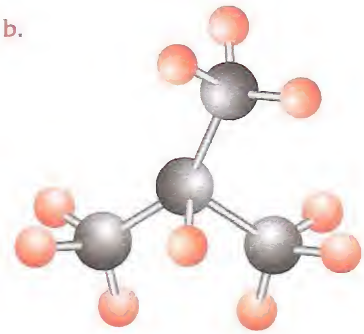
The first isomer, n – butane has an unbranched four carbon chain, but the second isomer isobutane has a methyl group on the second carbon atom.

The same lego blocks can be used to build different structures.

a.



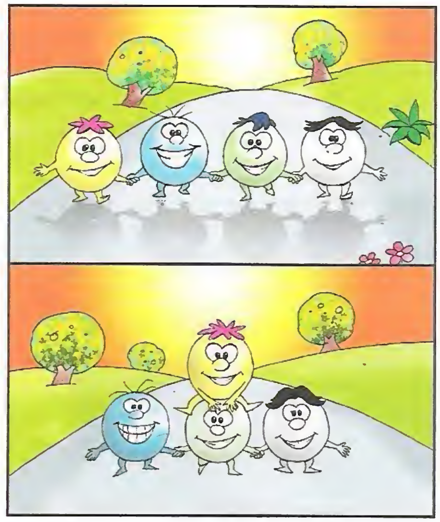
b.



Isomers of butane; n – butane(a) and isobutane(b)

In this case, there are two different possible structures for C_4H_{10}. These two compounds have the same molecular weight and number of atoms but different chemical and physical properties.

This is called structural isomerism. In general, as the number of "C" atoms increases, the number of isomers increases, too.



Isomers

Structure of the molecule	$CH_3-CH_2-CH_2-CH_2-CH_3$	$CH_3-CH_2-CH(CH_3)-CH_3$	$CH_3-C(CH_3)_2-CH_3$
Name of the molecule	n–pentane	2–methylbutane (isopentane)	2,2 dimethylpropane (neopentane)
Melting point (°C)	–130	–160	–17
Boiling point (°C)	36	28	9.5
Relative density (d_{water} = 1 g/mL)	0.626	0.620	0.613

Table 5 : *Isomers of pentane*

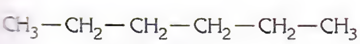
Alkane	Number of İsomers
C_4H_{10}	2
C_5H_{12}	3
C_6H_{14}	5
C_7H_{16}	9
C_8H_{18}	18
$C_{15}H_{32}$	4347
$C_{20}H_{42}$	366319
$C_{30}H_{62}$	4111846763
$C_{40}H_{82}$	62491178805831

Table 6 : *The number of possible isomers increases with increasing number of carbons in the molecule.*

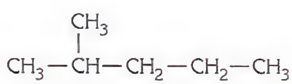
Example 6

Hexane, C_6H_{14}, has five isomers. Write the structural formulae and the IUPAC names of these isomers.

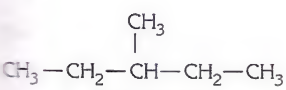
Solution



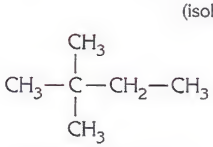
n – hexane



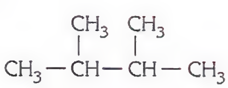
2 – methylpentane
(isohexane)



3 – methylpentane



2,2 – dimethylbutane
(neo–hexane)



2,3 – dimethylbutane

5. PHYSICAL PROPERTIES OF ALKANES

Alkanes are nonpolar molecules, hence van der Waals forces are responsible for attractions between the molecules. Increasing the number of carbon atoms causes an increase in the strength of the van der Waals forces. The first four members of the alkanes are gases, those with 5–17 carbons are liquids, and the rest are solids.

The boiling points, melting points and densities of alkanes increase directly with the increase in the number of carbon atoms.

Their densities are smaller than 1g/ml and they are generally colorless, tasteless and odorless.

Increasing of the number of branches in isomers decreases the boiling point. For example, n-pentane boils at 36°C, whereas isopentane boils at 28°C.

They are insoluble in water, but soluble in organic solvents such as benzene and carbon tetrachloride.

Name	Number of Carbon	Molecular Formula	Melting Point (°C)	Boiling Point (°C)	Relative density (at 20°C)
Methane	1	CH_4	–183	–162	
Ethane	2	CH_3CH_3	–172	–88.5	
Propane	3	$CH_3CH_2CH_3$	–187	–42	
Butane	4	$CH_3(CH_2)_2CH_3$	–135	0	
Pentane	5	$CH_3(CH_2)_3CH_3$	–130	36	0.626
Hexane	6	$CH_3(CH_2)_4CH_3$	–94.0	69	0.659
Heptane	7	$CH_3(CH_2)_5CH_3$	–90.5	98	0.684
Octane	8	$CH_3(CH_2)_6CH_3$	–57	126	0.703
Nonane	9	$CH_3(CH_2)_7CH_3$	–54	151	0.718
Decane	10	$CH_3(CH_2)_8CH_3$	–30	174	0.730

Table 7 : *Physical properties of the alkanes.*

Butane is used in lighters.

6. CHEMICAL PROPERTIES OF ALKANES

We know that another name for alkanes is paraffins which means "inert". Hence, as the name suggests, alkanes are chemically quite unreactive.

Alkanes don't react with dilute acids (HCl, H_2SO_4), active metals (Na, K), and strong oxidizing agents ($KMnO_4$, Na_2CrO_4). On the other hand, alkanes undergo combustion and substitution reactions with halogens easily. They can also be nitrated at high temperatures.

6.1. COMBUSTION REACTIONS

Alkanes produce CO_2 and H_2O when they are burnt. In these reactions, a large amount of energy is released. For this reason, natural gas, which contains a mixture alkanes, is a useful fuel. The general formula for a combustion reaction is;

$$\boxed{C_nH_{2n+2} + \frac{3n+1}{2} O_2 \longrightarrow n\,CO_2 + (n+1)\,H_2O}$$

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

The composition of natural gas varies in different localities. Its main component, methane, usually makes up 80% to 95% and the rest is composed of varying amounts of ethane, propane and butane.

Burning of hexane

6.2. SUBSTITUTION REACTIONS

In this type of reaction, an atom in a molecule is replaced with another atom or group. Alkanes may undergo substituon reactions with halogens and nitric acid. The first reactions are often called halogenation and the second nitration reactions.

In halogenation reactions, chlorine and bromine are generally used, since fluorine reacts very rapidly and produces a large amount of energy and iodine does not undergo substitution reactions. The general representation of a substitution reaction is:

$$\boxed{\underset{\text{Alkane}}{R-H} + \underset{\text{Halogen}}{X-X} \xrightarrow[\text{heat}]{\text{light}} \underset{\text{Alkyl halide}}{R-X} + HX}$$

When a large amount of heat and light is used, radicals of Cl and CH_4 are formed and the reaction occurs in a series of steps.

Step 1 : $Cl-Cl \xrightarrow{h\nu} Cl\cdot + Cl\cdot$

Step 2 : $Cl\cdot + CH_4 \xrightarrow{h\nu} CH_3\cdot + HCl$

Step 3 : $CH_3\cdot + Cl_2 \xrightarrow{h\nu} CH_3Cl + Cl\cdot$

If chlorine is still present

$$\underset{\text{Methyl chloride}}{CH_3Cl} \xrightarrow[\text{heat, light}]{Cl_2} \underset{\substack{\text{Dichloromethane}\\ \text{(Methylene chloride)}}}{CH_2Cl_2} \xrightarrow[\text{heat, light}]{Cl_2} \underset{\substack{\text{Trichloromethane}\\ \text{(Chloroform)}}}{CHCl_3} \xrightarrow[\text{heat, light}]{Cl_2} \underset{\substack{\text{Tetrachloromethane}\\ \text{(Carbontetrachloride)}}}{CCl_4}$$

Net reaction is : $CH_4 + 4Cl_2 \xrightarrow{\text{heat, light}} CCl_4 + 4HCl$

The C—H bonds in alkanes are broken to form nitroalkanes with nitric acid at 400°C or more.

$$\boxed{\underset{\text{Alkane}}{R-H} + HO-NO_2 \xrightarrow{425^\circ C} \underset{\text{Nitroalkane}}{RNO_2} + H_2O}$$

A mixture of propane and butane (LPG; liquefied petroleum gas) is used as fuel for cooking.

If propane is nitrated, a mixture of 1-nitropropane and 2-nitropropane, nitromethane and nitroethane is produced.

$$C_3H_8 + HNO_3 \xrightarrow{425^\circ C} \underset{\%25}{CH_3-NO_2} + \underset{\%10}{C_2H_5-NO_2} + \underset{\%25}{CH_3CH_2CH_2-NO_2} + \underset{\%40}{CH_3CH(CH_3)NO_2}$$

6.3. CRACKING REACTIONS

In the cracking process higher alkanes are converted into smaller alkanes and alkenes at high temperatures. When a catalyst is used in the process, it is known as catalytic cracking.

$$CH_3(CH_2)_8CH_3 \xrightarrow{\text{heat}} CH_3(CH_2)_6CH_3 + CH_2{=}CH_2$$

6.4. ISOMERIZATION

Catalytic isomerization converts straight–chained alkanes into branched chain ones. For example when we heat n–pentane using $AlCl_3$ as a catalyst isopentane is produced

$$\underset{\text{n–pentane}}{CH_3CH_2CH_2CH_2CH_3} \xrightarrow[AlCl_3]{\text{heat}} \underset{\text{2–methylbutane}}{CH_3\underset{\substack{|\\CH_3}}{C}HCH_2CH_3}$$

Example 7

When 2.2 g of an alkane is burnt completely 3.36 L of CO_2 is produced at STP. What is the molecular formula of this alkane? (C : 12, H : 1)

Solution

The general equation for the combustion of alkanes is;

$$C_nH_{2n+2} + \frac{3n+1}{2}O_2 \longrightarrow nCO_2 + (n+1)\,H_2O$$

Let us find the number of moles in 3.36 L of CO_2 at STP.

$$n_{CO_2} = \frac{3.36\ \text{L}}{22.4\ \text{L/mol}} = 0.15\ \text{mol}$$

We can now find the number of moles of alkane as:

1 mole alkane	n mole CO_2
x mole alkane	0.15 mole CO_2

$x \cdot n = 1 \cdot 0.15$

$x = \frac{0.15}{n}$ Molar mass of alkane $C_nH_{2n+2} = 12n + 2n + 2$

$$n_{C_nH_{2n+2}} = \frac{m}{M}$$

$$\frac{0.15}{n} = \frac{2.2}{12n + 2n + 2} \Rightarrow n = 3 \quad \text{The formula is } C_3H_8$$

Example 8

When 5 moles of a mixture of ethane and pentane gases are burnt, 19 moles of CO_2 are produced under the same conditions. What are the number of moles of each gas in the mixture?

Solution

We know that the ethane-pentane mixture is 5 moles. If we say that the number of moles of C_2H_6 is x, the number of moles of C_5H_{12} will be (5-x) moles.

Equations for the combustion of ethane and pentane are:

$$2\,C_2H_6 + 7\,O_2 \longrightarrow 4\,CO_2 + 6\,H_2O$$

2 moles C_2H_6 — 4 moles CO_2

x mole — 2 x moles

$$1\,C_5H_{12} + 8\,O_2 \longrightarrow 5\,CO_2 + 6\,H_2O$$

1 mole C_5H_{12} — 5 moles CO_2

$(5-x)$ mole — $5(5-x)$ mole

Then we can find x as we know the total number of moles of CO_2.

$2x + 5(5-x)$ moles $= 19$ $\qquad 6 = 3x$

$x = n_{C_2H_6} = 2$ moles $\qquad n_{C_5H_{12}} = 3$ moles

Example 9

11 g of a saturated hydrocarbon occupies 11.2 L at 273°C and 1 atm. How many moles of water will be formed when this hydrocarbon is burnt?

Solution

Let us find the number of moles of the hydrocarbon.

P : 1 atm $\qquad$ T : 273 + 273 = 546 K

V : 11.2 L $\qquad$ R : $22.4/273\ \text{L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$

$$PV = n \cdot R \cdot T$$

$$1\ \text{atm} \cdot 11.2\ \text{L} = n \cdot \frac{22.4\ \ \text{L} \cdot \text{atm}}{273\ \ \text{mol} \cdot \text{K}} \cdot 546\ \text{K}$$

$$n = 0.25\ \text{mol}$$

We can now find the molecular weight of the hydrocarbon

$$M = \frac{m}{n} \Rightarrow M_{C_nH_{2n+2}} = \frac{11\ \text{g}}{0.25\ \text{mol}} = 44\ \text{g/mol}$$

To find n, let's use the mass equation.

$12n + 2n + 2 = 44 \longrightarrow n = 3 \quad C_3H_8$

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

According to this equation

1 mole C_3H_8	produce 4 mol H_2O
0.25 mole	x

$$x = n_{H_2O} = \frac{0.25 \text{ mol x } 4 \text{ mol}}{1 \text{ mol}} \Rightarrow n_{H_2O} = 1 \text{ mole}$$

7. PREPARATION OF ALKANES

Crude oil.

Mixtures of alkanes obtained from petroleum, natural gas and coal can be used as fuel.

Crude oil is a mixture of alkanes and aromatic hydrocarbons which have carbon atom numbers ranging from 1 to 40. In different regions of the world the composition of oil is different. Crude oil is separated into its components by a method known as fractional distillation.

Natural gas is a gas mixture which is obtained from underground reservoirs. It consists of methane, a small proportion of ethane and some other gases.

Alkanes, that are generally extracted from crude oil by fractional distillation, can also be produced in the laboratory.

7.1. WURTZ SYNTHESIS

The Wurtz synthesis is a method of producing alkanes by the reaction of alkyl halides with sodium.

This method was first carried out by Adolph Wurtz in 1885.

$$\underset{\text{alkyl halide}}{2R-X} + 2Na \longrightarrow \underset{\text{alkane}}{R-R} + 2NaX$$

$$\underset{\text{methyl chloride}}{2CH_3-Cl} + 2Na \longrightarrow \underset{\text{ethane}}{CH_3-CH_3} + 2NaCl$$

In the Wurtz synthesis, a complex alkane is produced from smaller ones. Hence methane cannot be produced in this way. If different alkyl halides are used in the Wurtz synthesis, three different alkanes can be formed. For this reason, this method is more useful for alkanes which have even numbers of carbon atoms.

Bitumen extracted by the fractional distillation of petroleum is used in asphalt roads.

$$\begin{matrix} 3CH_3-Cl \\ \\ 3C_2H_5-Cl \end{matrix} + 6Na \longrightarrow \begin{matrix} CH_3-CH_3 \text{ (Ethane)} \\ CH_3-C_2H_5 \text{ (Propane)} \\ C_2H_5-C_2H_5 \text{ (Butane)} \end{matrix} + 6NaCl$$

Two different alkyl halides produce three different alkanes.

Example 10

Which alkyl halides should be used to obtain hexane by the Wurtz synthesis? Explain.

Solution

The total number of carbon atoms in the reactants must be equal to number of carbon atoms in the product in a Wurtz synthesis. Hexane, C_6H_{14}, contains 6 carbon atoms. So, the sum of carbon atoms that will be used in forming hexane must be 6. These numbers may be (1–5), (2–4) or (3–3). According to this:

$-CH_3$ and $-C_5H_{11}$ (methyl; pentyl)

$-C_2H_5$ and $-C_4H_9$ (ethyl; butyl)

$-C_3H_7$ and $-C_3H_7$ (propyl; propyl)

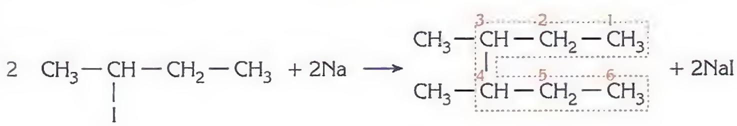
may be used to produce hexane by the Wurtz method. If it is desired that the production of hexane be as efficient as possible, the most suitable alkyl groups are propyl-propyl ($-C_3H_7$ and C_3H_7). So propyl chloride would be the recommended starting product.

Example 11

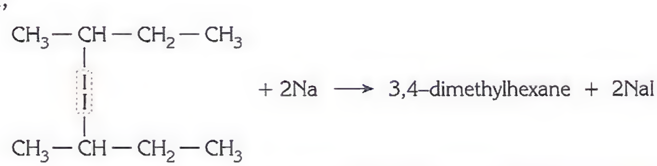
What is the molecular formula and the name of the hydrocarbon that is obtained from the reaction of 2-iodobutane with an excess amount of sodium metal? Write out the reaction and explain.

Solution

In this Wurtz reaction, alkyl groups of these alkyl halides will bond to each other on the second carbon and 3,4 - dimethylhexane will be formed.



Or,



THE PIONEERS

Charles Adolph Wurtz

(1817-1884)

Wurtz was French and the first chemist to put forward the atomic theory in France. He worked particularly on organic chemistry and discovered amines in 1849, glycol in 1872 and alcohols in 1872. He showed that glycerine is a triol (an alcohol with three–OH groups) and explained its formula. He also devised a method for producing alkanes which is named after him.

THE PIONEERS

Victor Grignard
(1871-1935)

He was a French chemist who discovered organometallic compounds. They are now known as Grignard reagents.

He won the Nobel Prize in 1912 for his discovery.

7.2. HYDRATION OF GRIGNARD COMPOUNDS

In 1901, Victor Grignard, prepared an organomagnesium halide by the reaction of an organic halide with magnesium metal in dry ether.

$$\underset{\text{methyl iodide}}{\mathrm{H-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-I}} + \mathrm{Mg} \xrightarrow{\text{dry ether}} \underset{\text{methylmagnesium iodide}}{\mathrm{H-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-MgI}}$$

These compounds (alkyl magnesium halides) are now called Grignard reagents in the honor of Victor Grignard.

Grignard reagents are generally prepared by the following reaction:

$$\underset{\text{alkyl halide}}{\mathrm{R-X}} + \mathrm{Mg} \xrightarrow{\text{dry ether}} \underset{\substack{\text{alkyl magnesium halide}\\ \text{(Grignard reagent)}}}{\mathrm{R-MgX}}$$

Grignard compounds react with water, alcohol or acids to form alkanes.

$$\underset{\text{Grignard reagent}}{\mathrm{R-MgX}} + \mathrm{H-OH} \longrightarrow \underset{\text{alkane}}{\mathrm{R-H}} + \underset{\substack{\text{magnesium hydroxy}\\ \text{halide}}}{\mathrm{Mg(OH)X}}$$

The two reactions may be combined,

For example:

$$\underset{\text{ethyl bromide}}{\mathrm{C_2H_5-Br}} \xrightarrow[\text{dry ether}]{\mathrm{Mg}} \underset{\substack{\text{ethylmagnesium}\\ \text{bromide}}}{\mathrm{C_2H_5-MgBr}} \xrightarrow{\mathrm{H_2O}} \underset{\text{ethane}}{\mathrm{C_2H_5-H}} + \mathrm{Mg(OH)Br}$$

Example 12

Prepare the following alkanes by using Grignard reagents.

a. C_3H_8 b. $\mathrm{CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3}$

Solution

a. $C_3H_7Cl + Mg \xrightarrow[\text{ether}]{\text{dry}} C_3H_7MgCl \xrightarrow{H_2O} C_3H_7-H + Mg(OH)Br$

b. $\mathrm{CH_3-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-Br + Mg \rightarrow CH_3-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-MgBr \xrightarrow{H_2O} CH_3-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-H + Mg(OH)Br}$

7.3. REDUCTION OF ALKYL HALIDES

Alkyl halides produce alkanes when they are reacted with reducing agents, such as Zn, in dilute acid.

So in the reaction below Zn is acting as a reducing agent and the halogen in the alkyl halide is replaced by the hydrogen from the dilute acid.

$$\underset{\text{alkyl halide}}{2R - X} \xrightarrow[H^+]{Zn} \underset{\text{alkane}}{2R - H} + ZnX_2$$

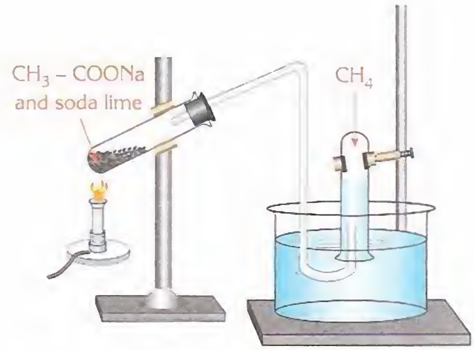
$$\underset{\text{2 – bromobutane}}{2CH_3CH_2\underset{|\atop Br}{C}HCH_3} \xrightarrow[H^+]{Zn} \underset{\text{n–butane}}{2CH_3CH_2\underset{|\atop H}{C}HCH_3} + ZnBr_2$$

7.4. HEATING THE METAL SALTS OF CARBOXYLIC ACIDS

When sodium salts of carboxylic acids are heated with NaOH, alkanes are produced.

$$\underset{\text{sodium salt of a carboxylic acid}}{R - COONa} + NaOH \xrightarrow[CaO]{heat} \underset{\text{alkane}}{R - H} + Na_2CO_3$$

$$\underset{\text{sodium propanoate (sodium salt of propanoic acid)}}{C_2H_5 - COONa} + NaOH \xrightarrow[CaO]{heat} \underset{\text{ethane}}{C_2H_6} + Na_2CO_3$$



Methane is prepared by heating CH_3COONa with soda-lime.

$$CH_3COONa + NaOH \xrightarrow{heat} CH_4 + Na_2CO_3$$

Soda-lime is a white granular mixture of calcium hydroxide and sodium hydroxide.

Example 13

Complete the equations for the following reactions showing the products

a. Propyl bromide + Mg $\longrightarrow$ .... + H_2O $\rightarrow$ .... + Mg(OH)Br

b. C_3H_7 – COONa + NaOH $\xrightarrow[CaO]{heat}$ ....

Solution

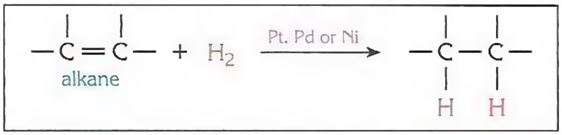
a. $C_3H_7 - Br + Mg \longrightarrow \underset{\text{Grignard reagent}}{C_3H_7 - MgBr}$

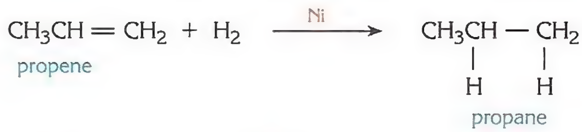
$C_3H_7 - MgBr + H - OH \longrightarrow \underset{\text{propane}}{C_3H_8} + Mg(OH)Br$

b. $\underset{\text{Sodium butanoate (Sodium salt of butanoic acid)}}{C_3H_7 - COONa} + NaOH \xrightarrow[CaO]{heat} \underset{\text{propane}}{C_3H_8} + Na_2CO_3$

7.5. HYDROGENATION OF UNSATURATED HYDROCARBONS

When unsaturated hydrocarbons (alkenes and alkynes) are saturated, alkanes are produced. In this type of reaction, Ni, Pt or Pd are used as a catalyst.





$$CH \equiv CH + 2H_2 \xrightarrow{Ni} CH_3 - CH_3$$

ethyne ethane

Example 14

2 moles of a mixture of ethane (C_2H_6) and propene (C_3H_6) is treated with excess H_2 gas. 0.5 mole of H_2 is used and all the mixture becomes saturated. What is the mass of propene in the original mixture?

(C : 12; H : 1)

Solution

Ethane is a saturated hydrocarbon and propene is an unsaturated one. So, when this ethane – propene mixture is treated with H_2, only propene reacts with the hydrogen.

The reaction is as follows;

$$CH_3-CH=CH_2 + H_2 \longrightarrow CH_3-CH_2-CH_3$$

1 mole C_3H_6 reacts with 1 mole H_2

x mole C_3H_6 reacts with 0.5 mole H_2

---

x = 0.5 mole of C_3H_6 and 1.5 mole of C_2H_6

$m = n \times M$

$m = 0.5 \text{ mol} \cdot 42 \text{ g/mol}$

$m = 21 \text{ grams}$

Example **15**

11.2 L of H_2 at STP is required to saturate a 0.4 mol mixture of C_2H_4 (ethylene) and C_2H_2 (ethyne).

What is the mole percentage of ethylene in the mixture?

Solution

The reactions of ethylene and ethyne with hydrogen are as follows.

$$\underset{x\text{ mole}}{C_2H_4} + \underset{x\text{ mole}}{H_2} \longrightarrow C_2H_6$$

$$\underset{y\text{ mole}}{C_2H_2} + \underset{2y\text{ mole}}{2H_2} \longrightarrow C_2H_6$$

The number of moles of H_2 reacted is;

$$n_{H_2} = \frac{11.2\text{ L}}{22.4\text{ mol/L}} = 0.5\text{ mol}$$

According to the reactions, x mole ethylene (C_2H_4) reacts with x mol of H_2, and y mol of ethyne (C_2H_2) reacts with 2y mol of H_2 to produce ethane (C_2H_6).

The number of moles of C_2H_4 and C_2H_2 ;

$x + y = 0.4$ mol

Total number of moles of H_2 ;

$x + 2y = 0.5$ moi

$x + y = 0.4$

$x + 2y = 0.5$

$x = 0.3 \quad y = 0.1$

So the mole % of x (ethylene) is $= \dfrac{0.3}{0.4} \cdot 100 \Rightarrow 75\%$ ethylene (C_2H_4)

8. METHANE

Methane, the first member of the alkane is mainly found in mines and in natural gas which is formed over petroleum reserves. It is also known as marsh gas and is formed by the decomposition of plants in the absence of oxygen.

8.1. PHYSICAL PROPERTIES

Methane is a colorless and odorless gas. It is insoluble in water, but soluble in benzene and gasoline. It is less dense than air and has a boiling point of –161,5°C.

8.2. CHEMICAL PROPERTIES

A 10-15% mixture of methane in air may cause an explosion. Explosions in mines are known as "firedamp explosions". Also, huge garbage dumps in cities can cause dangerous explosions due to the production of methane. Methane burns with a light blue flame and is decomposed when it is heated strongly.

$$CH_4 \xrightarrow{1500\ °C} C_2H_2 + H_2$$

$$CH_4 \xrightarrow{1000\ °C} C + H_2$$

$$2CH_4 + O_2 \xrightarrow[260°C,\ 100\ atm]{catalyst} 2CH_3OH$$

8.3. PREPARATION METHODS

Methane can be produced by some of the general alkane production methods. In addition there are three special methods for the production of methane;

a. The reaction of aluminum carbide in acidic solution produces methane.

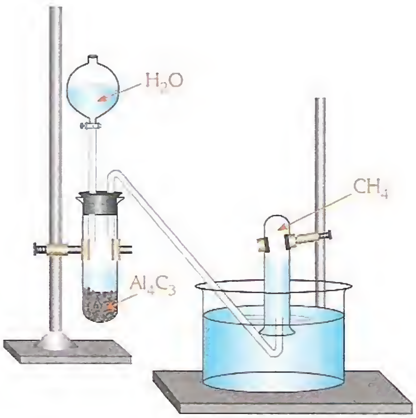
$$Al_4C_3 + 12H_2O \xrightarrow{H^+} 4Al(OH)_3 + 3CH_4\uparrow$$

b. When a mixture of CO and H_2 gas is passed over Nickel (Ni) or Cobalt (Co) at 300–400° C, methane is produced.

$$CO + 3H_2 \xrightarrow[300-400°C]{Ni} CH_4 + H_2O$$

c. Methane can also be obtained from the reaction of carbon with hydrogen under high temperature and pressure in the presence of a nickel catalyst.

$$C + 2H_2 \underset{pressure,\ heat}{\overset{Ni}{\rightleftharpoons}} CH_4$$



CH_4 is formed by the reaction of Al_4C_3 with water in acidic solution.

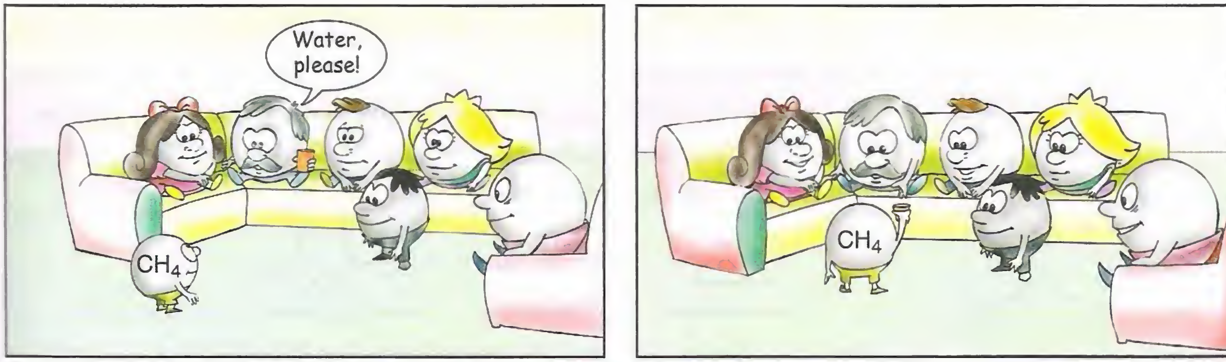
EXTRA

BIOGAS

Biogas is the general term for gases produced by the fermentation of manure and plant material under anaerobic conditions. When plant material (manure, straw, vegetables) decays in the absence of air, bacteria produce biogas. Biogas is a mixture of 60% methane and carbon dioxide.

The organic residue remaining of the end of the anaerobic digestion process can be further processed to make an excellent soil conditioner.

Methane gas may be formed spontaneously in muds and marshes by the decomposition of organic substances. The gas may be used to produce energy in order to run houses.



Methane is the smallest member of the organic family.

Example 16

What is the yield when 43.2 g of Al_4C_3 reacts with excess water to produce 9.6 g of CH_4 gas? (Al_4C_3 : 144 g/mol, CH_4 : 16 g/mol)

Solution

Let us find the number of moles of Al_4C_3 and CH_4.

$$n_{Al_4C_3} = \frac{m}{M} = \frac{43.2 \text{ g}}{144 \text{ g/mol}} = 0.3 \text{ mol}$$

$$n_{CH_4} = \frac{m}{M} = \frac{9.6 \text{ g}}{16 \text{ g/mol}} = 0.6 \text{ mol}$$

$$Al_4C_3 + 12H_2O \longrightarrow 4Al(OH)_3 + 3CH_4\uparrow$$

1 mol of Al_4C_3 gives 3 moles of CH_4

0.3 mole x

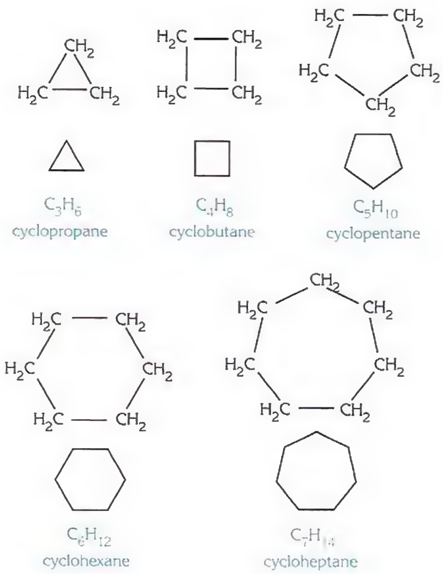
$x = n_{CH_4} = 0.9$ mol

The first mole number found from the given mass is the experimental amount and the second amount is the theoretical amount. We find the yield of the reaction by dividing the first by the second.

$$\text{yield} = \frac{n_{CH_4}}{n_{Al_4C_3}} = \frac{0.6 \text{ mole}}{0.9 \text{ mole}} = 0.67 \text{ or } 67\%$$

9. CYCLOALKANES

Carbon atoms in alkanes can be attached to one another in a ring formation and such compounds are called cycloalkanes. The general formula of cycloalkanes is C_nH_{2n}.



Names of some cycloalkanes

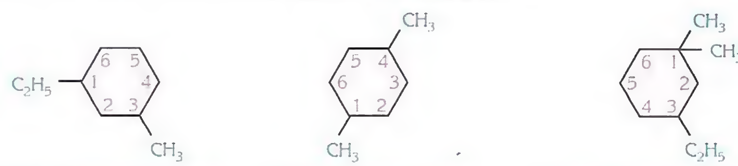
9.1. NOMENCLATURE OF CYCLOALKANES

Cycloalkanes are named by adding the prefix cyclo – to the names of the alkanes. For example, the cycloalkane with three carbon atoms is called cyclopropane.

If there is a substituent attached to the ring, we name them as, alkylcycloalkanes, halocycloalkanes, etc. For example,

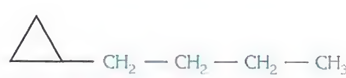
chlorocyclopropane   bromocyclobutane   methylcyclopentane   ethylcyclohexane

When two substituents exist, the ring is numbered starting with the substituent first in the alphabet, and numbered in the direction which gives the lowest number for the second substituent. For example,

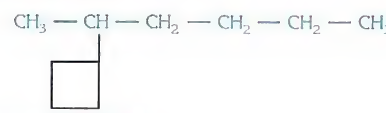


1–ethyl–3–methylcyclohexane   1,4–dimethylcyclohexane   3–ethyl–1,1 dimethylcyclohexane (not 1–ethyl–3,3–dimethylcyclohexane)

When the number of carbon atoms in the substituents is more than that in the cycloalkane itself then they are named as cycloalkylalkanes.



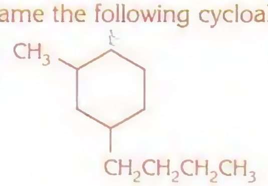
1–cyclopropylbutane
(not butylcyclopropane)

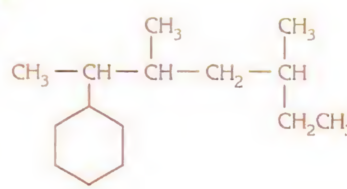


2–cyclobutylhexane
(not hexylcyclobutane)

Example 17

Name the following cycloalkanes.

a. 

b. 

Solution

a. 1–butyl–3–methylcyclohexane. Substituents are attached to the 1st and 3rd carbon atoms of the ring. The name of butyl comes before methyl alphabetically. So, the numbering starts from the butyl group.

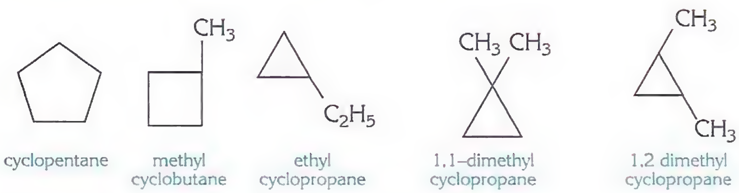
b. 2–cyclohexyl–3,5–dimethylheptane. The number of carbon atoms is 7 in the straight-chained alkane and 6 in cycloalkane. Hence, it must be named as a cycloalkylalkane.

Example 18

C_5H_{10} is a cycloalkane. It has 5 structural isomers. Show them.

Solution

The 5 isomers of C_5H_{10} can be shown as follows.



Each isomer has the C_5H_{10} formula.

9.2. PHYSICAL PROPERTIES

The melting points, boiling points and densities of cycloalkanes are different from the alkanes possessing the same number of carbon atoms.

For example; the melting point of heptane is –90.5°C, the boiling point is 98.4°C and the density is 0.684 g/mL; whereas for cycloheptane these values are –12°C, 118.5°C and 0.808 g/mL respectively.

Some physical properties of first five members of the cycloalkanes are given in table 8.

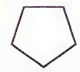
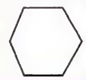
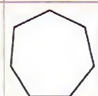
Cycloalkane	Structure	M.P. (°C)	B.P. (°C)	Density (20°C)
Cyclopropane		–127	–33	1.809 g/mL
Cyclobutane		–80	13.1	0.703 g/mL
Cyclopentane		–94.4	49.3	0.746 g/mL
Cyclohexane		6.47	80.7	0.778 g/mL
Cycloheptane		–12	118.5	0.809 g/mL

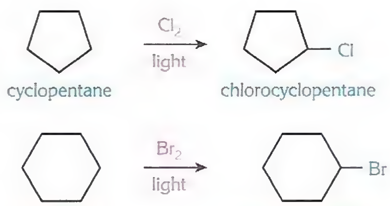
Table 8 : *The first five cycloalkanes and some of their physical properties*

Cyclopentane is widely used in producing non–CFC refrigerators, freezers and cold storage and tubing insulating materials.

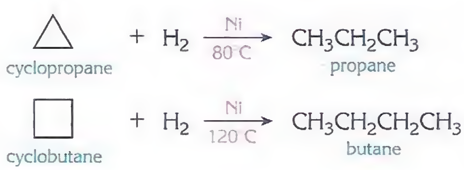
9.3. CHEMICAL PROPERTIES

The chemical properties of cycloalkanes show some differences from those of alkanes.

1. Cycloalkanes that have more than five carbon atoms undergo substitution reactions. In the substitution reactions of alkanes there can be more than one product, but in cycloalkanes, there can only be a single product.



2. Cycloalkanes which have four or three carbon atoms undergo addition (hydrogenation) reactions with a catalyst.



The cycloalkane having bigger ring strain undergoes the reaction more easily.

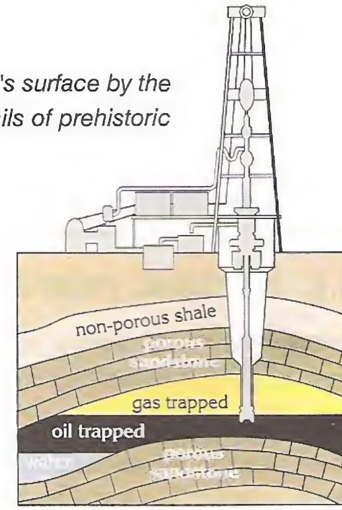
When bromine is added to cyclohexane, the bromine dissolves as it undergoes a substitution reaction and the product forms as a red-brown precipitate.

PETROLEUM

Petroleum, or crude oil, is a naturally occurring bituminous liquid composed of many different organic compounds. Liquid petroleum, depending upon the percentages of compounds, is a green-dark brown color of variable darkness.

Formation of Petroleum

Petroleum is formed underneath the Earth's surface by the decomposition of marine organisms and fossils of prehistoric animals and plants. The remains of tiny organisms that live in the sea, or land organisms that are carried down to the sea in rivers, are trapped by sands at the sea bottom.



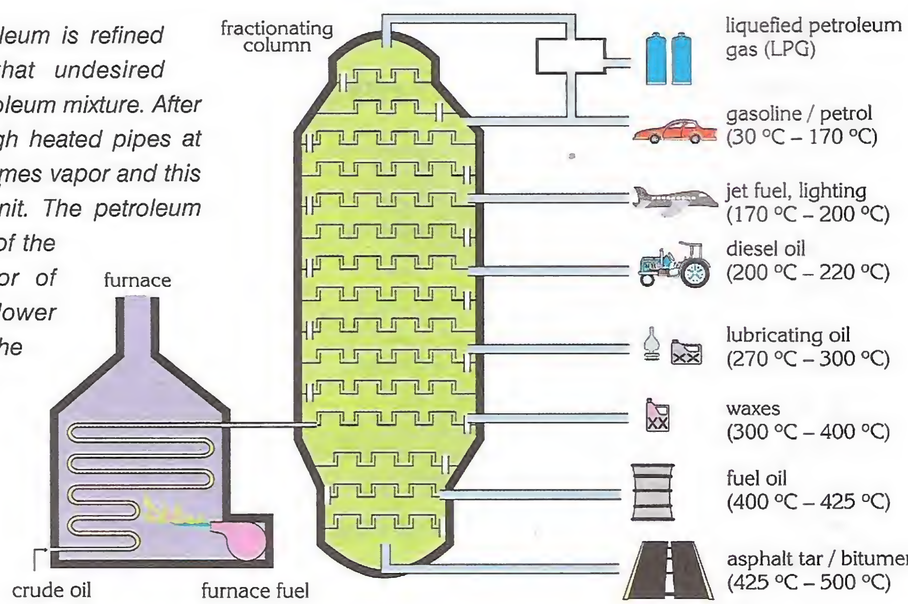
These deposits become the main source of crude oil. As additional deposits build up, the pressure on the ones below increase a thousand fold and temperature reaches a hundred degrees. The remains of the dead organisms are transformed into crude oil and natural gas.

Refining

Crude oil in its natural form can only be used as a fuel, and not in any other areas.

Because it consists of many different substances with different densities, petroleum can be separated into its components by fractional distillation.

Before fractional distillation, petroleum is refined by a pre-distillation method so that undesired components are driven out of the petroleum mixture. After that, the petroleum is pumped through heated pipes at 350-400⁰ C. Here, the petroleum becomes vapor and this is sent to the fractional distillation unit. The petroleum vapor starts rising to the upper parts of the fractional distillation unit. The vapor of petroleum cools down at lower temperatures; the uppermost part of the distillation unit is the place for gases (methane, ethane, propane and butane), which have boiling points lower than 20°C; C_3H_8 and C_4H_{10} are separated from each other at high pressures and stored in canisters for home use.



SUPPLEMENTARY QUESTIONS

1. What is the general formula that describes the alkanes?

2. Write the molecular and structural formula and the Lewis dot structure of the alkane containing 3 carbon atoms.

3. Calculate the molar mass of the alkane that has 12 hydrogen atoms.

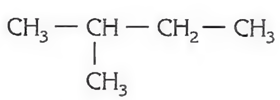
4. 0.25 mole of an alkane weighs 35.5 g. Find its molecular formula.

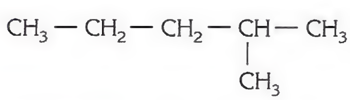
5. An alkane contains 20% hydrogen by mass. Find the molecular formula of this compound.

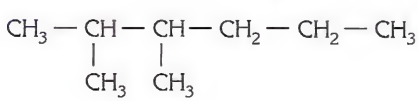
6. What is the molecular formula of the alkane of which one fourth is hydrogen by mass?

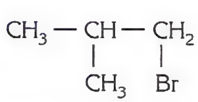
7. Write the names of the first ten members of aliphatic unbranched alkane series.

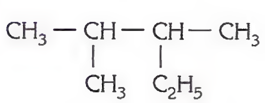
8. Name the following compounds using the IUPAC system.

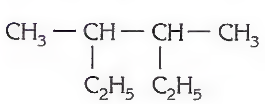
a. 

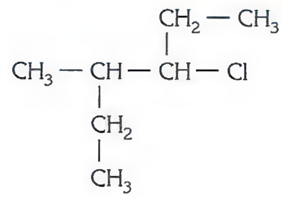
b. 

c. 

d. 

e. 

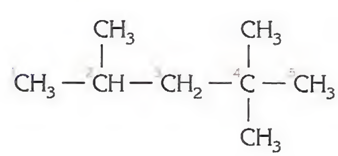
f. 

g. 

9. Draw the structural formulae of the following compounds:
   a. 3–methylpentane
   b. 2,3–dimethylbutane
   c. 3,4–dibromohexane
   d. 2–bromo–2–methylpropane
   e. 2,2,3–trimethylbutane
   f. 1,1–dichloro–3–ethyl–2,4–dimethylpentane

10. There are one methyl, two ethyl and one propyl group attached to a carbon atom. What is the IUPAC name of this compound.

11. Classify the numbered carbon atoms according to the number of bonds they form with other carbon atoms.



12. What is isomerism? Give the structural formulae of two compounds which are isomers.

13. Although the molar mass of butane is greater than that of water, butane is a gas at room temperature.
    Explain the reason.

14. What are the differences between compounds that are structural isomers of each other?

15. I. Butane
II. Pentane
III. Isobutane
Compare these compounds with respect to their;
a. Boiling points
b. Densities
c. Melting points

16. There are three different structures of pentane: n-pentane, isopentane and neopentane. Their boiling points are 36°C, 28°C and 9.5°C respectively. Explain this difference.

17. How do the number of carbon atoms affect the physical properties of alkanes?

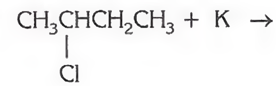
18. Heptane has 9 isomers. Draw their structural formulae name all these compounds.

19. Show all the possible structural formulae of C_3H_7Cl.

20. How many isomers does $C_2H_4Cl_2$ have? Show the formulae of these isomers.

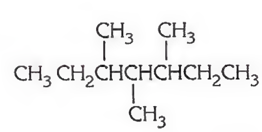
21. Complete the equations and name the products
a. Isopropyl chloride + Na $\rightarrow$
b. Sodium butanoate + NaOH $\rightarrow$
c. Propene + H_2 $\rightarrow$
d. Butyl magnesium iodide + H_2O $\rightarrow$

22. Explain how you could obtain butane by;
a. The Wurtz synthesis
b. Hydrolysis of grignard compounds
c. Decarboxylation of carboxylic acid salts

23. Complete and balance the following reactions.
a. $CH_3CH_2CH_2Br + Na \rightarrow$
b. $CH_3CH_2MgBr + HBr \rightarrow$
c. 

24. How many grams of Al_4C_3 must be used to obtain 560 cm^3 CH_4 gas at STP by a reaction with a 75% yield?

25. Which alkyl halide pairs may be used to obtain 2–methylbutane?

26. 

Which alkyl halide pairs might be used to obtain 3,4,5–trimethylhexane? (Give at least 3 pairs)

27. What are the names of the compounds which are formed by the reaction of 2 – bromopropane and 2 – methyl – 3 – chlorobutane with a sufficient amount of Na?

28. What is the molecular weight of the compound that is produced by 2 moles of 2 – bromopropane and excess Na? Give its IUPAC name.

29. Write the formula of the compound that is formed by the reaction of ethane with nitric acid at high temperature?

30. How many grams of water is produced by burning 1.12 liters of C_3H_8 in air at STP?

31. What volume of air is needed to burn 56 liters of butane gas at STP?

32. When 0.1 mole of a saturated hydrocarbon, which has a number of carbon atoms equal to half its number of hydrogen atoms, is burned, 9 grams of water are obtained. What is the molecular formula and the name of this compound?

33. When equal moles of a mixture of CH_4 and C_3H_8 gases are burned, 44.8 L of CO_2 gas at STP is formed. Using this information,

a. Find the number of moles of methane.

b. Find the volume of ethane at STP.

c. What is the volume of oxygen used?

d. What is the mass of water produced?

34. 40% of a liquified petroleum gas is composed of propane and the rest is butane. This mixture is put into a room which has a size of 2m x 3m x 4m. How many grams of this mixture can be burned with the air in this room at STP? (remember that 21% of air by volume is oxygen)

35. At STP 33.6 liters of hydrogen gas is used to saturate 24 grams of a C_2H_4 and C_2H_2 mixture. What is the mass percentage of C_2H_4 in the mixture?

36. For a mixture composed of ethylene (C_2H_4) and propylene (C_3H_6);

I. 3 moles of oxygen is used to burn it completely.

II. 20.16 L H_2 at STP is used to saturate it completely.

Find the mass of the initial mixture.

37. In order to saturate 3 moles mixture of CH_4 and ethylene (C_2H_4) 2 moles of H_2 is needed. What is the mole percentage of ethylene in the starting mixture?

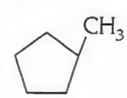
38. Give some information about petroleum and natural gas.

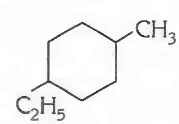
39. 7.25 grams of a saturated hydrocarbon occupies 2.05 L under 2 atm pressure and 127°C. How many liters of CO_2 are obtained when 0.25 mol of this hydrocarbon is burned at STP? (hint: P.V = n.R.T)

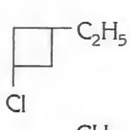
40. When propane and butane are burned, 18 liters of CO_2 is produced at STP. What are the volumes of each compound if the total volume of propane and butane is 5 L at STP?

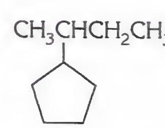
41. Draw the structural formulae of the cyclic isomers of C_6H_{12}. (There are 8 of them)

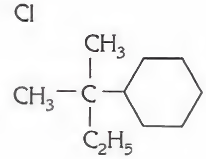
42. Name the following compounds.

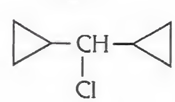
a. 

b. 

c. 

d. 

e. 

f. 

MULTIPLE CHOICE QUESTIONS

1. How many sigma bonds are there in a molecule of a saturated aliphatic hydrocarbon with 5 carbon atoms?

A) 5 B) 8 C) 12 D) 16 E) 17

2. 3 methyl groups and 1 ethyl group are attached to one carbon atom. This compound can be named as;

I. 2,2 - dimethylbutane

II. Neohexane

III. Isopentane

A) I only B) II only C) I and II D) II and III E) I, II and III

3. Which one of the following is not an isomer of n-hexane?

A) $CH_3-\underset{\substack{|\\ CH_3}}{CH}-CH_2-CH_2-CH_3$

B) $CH_3-CH_2-\overset{\substack{CH_3\\ |}}{CH}-CH_2-CH_3$

C) $CH_3-\underset{\substack{|\\ CH_3}}{CH}-\underset{\substack{|\\ CH_3}}{CH}-CH_3$

D) $CH_3-CH_2-\underset{\substack{|\\ CH_3}}{CH}-\underset{\substack{|\\ CH_3}}{CH}-CH_3$

E) $CH_3-\overset{\substack{CH_3\\ |}}{\underset{\substack{|\\ CH_3}}{C}}-CH_2-CH_3$

4. I. Chloroethane

II. Propane

III. Methane

Which of the above compounds do not have isomers?

A) I only B) I and II C) II and III D) I and III E) I, II and III

5. Which one of the following compounds has isomers?

A) Methane B) Methyl chloride C) Ethane D) Propane E) Butane

6. I. Molecular weight

II. Molecular formula

III. Density

IV. Boiling point

X and Y are isomers. Which two of the given properties are exactly the same for X and Y?

A) I and II B) II and III C) I and III D) III and IV E) II and IV

7. I. They are insoluble in water because they are nonpolar.

II. Van der Waals forces exist between the molecules.

III. Boiling point increases with increasing number of carbon atoms.

Which of the given statements is/are correct for alkanes?

A) I only B) II only C) I and II D) II and III E) I, II and III

8. Compare the boiling points of:

I. n - pentane

II. isopentane

III. neopentane

A) I > II > III B) III > II > I C) I > III > II D) III > I > II E) II > III > I

9. When 8.8 grams of an alkane is burned, 26.4 grams of CO_2 is produced.

What is the molecular formula of this alkane?

A) C_3H_6 B) C_2H_6 C) C_3H_8 D) C_4H_{10} E) C_5H_{12}

10. I. The alkane that produces 5 moles of water when 1 mole is burned is C_4H_{10}

II. The alkane that gives 1 mol of CO_2 when 0.5 mole is burned is C_2H_6.

III. The alkane that gives 22.4 L CO_2 (at STP) when 0.25 mole is burned is C_4H_{10}.

Which of the above is/are correct?

A) I only B) I and II C) II and III D) I and III E) I, II and III

11. Which one of the given compounds cannot be produced by a Wurtz reaction?

A) C_6H_{14} B) C_4H_{10} C) C_3H_8 D) C_2H_6 E) CH_4

12. To produce 2 - methylpropane by a Wurtz reaction, which two alkyl halides should be reacted together?

I. 1 - chloropropane

II. Methyl chloride

III. 2 - chloropropane

IV. Ethyl chloride

A) I and III B) II and III C) I and IV D) II and IV E) I and II

13. Which of the following might be produced by the reaction of C_2H_5Cl and C_3H_7Cl with Na?

I. CH_4

II. C_4H_{10}

III. C_5H_{12}

A) I only B) II and III C) I and III D) I and II E) I, II and III

14. I. $CH_2{=}CH_2 + H_2 \longrightarrow C_2H_6$

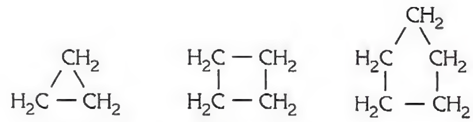
II. $2CH_3Br + 2Na \longrightarrow C_2H_6 + 2NaBr$

III. $C_2H_5Cl + KOH \longrightarrow C_2H_6 + KCl$

Which of the given reactions is/are redox reactions?

A) I only B) II only C) I and II D) II and III E) I, II and III

15.



cyclopropane I. | cyclobutane II. | cyclopentane III.

Which of the above names is/are correct?

A) I only B) I and II C) II and III D) I and III E) I, II and III

16. How many grams of Al_4C_3 must react with water to produce 6.72 L of CH_4 gas at STP?

A) 14.4 B) 28.8 C) 43.2 D) 57.6 E) 100.8

17. Which of the following methods can be used to produce methane?

I. From its elements using catalysts

II. Addition of H_2 to alkynes

III. The reaction of CO_2 with H_2O

A) I only B) I and II C) II and III D) I and III E) I, II and III

18. The molar mass of an alkyl bromide is 123 g/mol. Which of the compounds below can be produced from the reaction of this alkyl bromide with Na?

(H : 1, C : 12, Br : 80)

A) Ethane B) Propane C) Sodium propionate D) Heptane E) 2,3 - dimethylbutane

PUZZLE

CRISS – CROSS PUZZLE

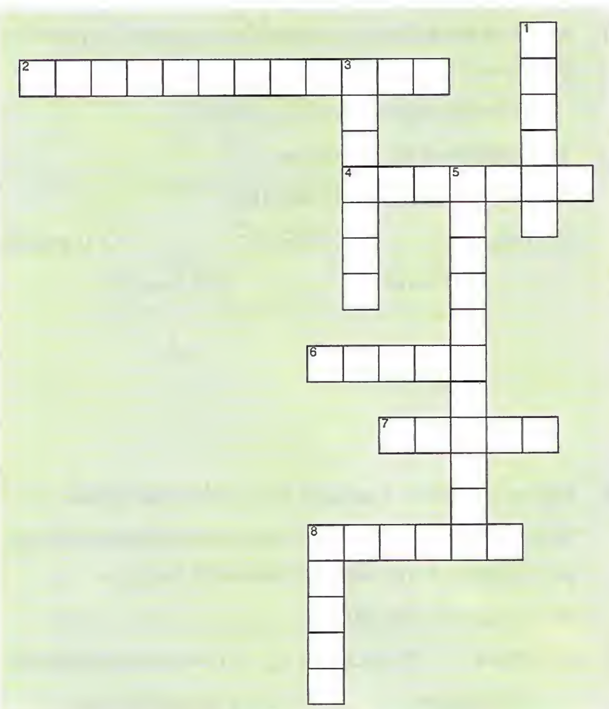
Solve the clues and place your answers in their correct positions in the grid.

CLUES ACROSS

2. A reaction where one atom of a molecule is replaced by a different atom.
4. The simplest alkane.
6. It is the abbreviation for the international union of pure and applied chemistry.
7. This synthesis is used while producing alkanes by the reaction of alkyl halides with sodium.
8. This homologous series consists of saturated aliphatic hydrocarbons.

CLUES DOWN

1. It is the sixth member of the alkanes.
3. These are the compounds which have the same molecular formula but different structural formulae.
5. A compound whose molecules consist of only carbon and hydrogen atoms.
8. If one hydrogen is removed from an alkane, this group is formed.



WORD SEARCH

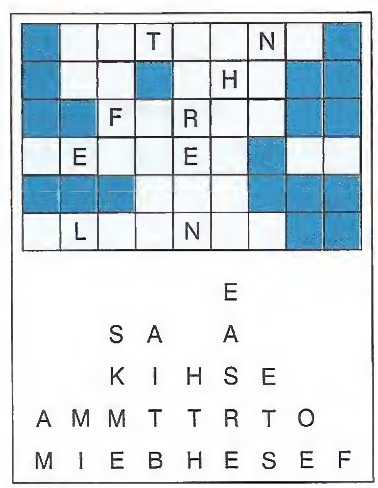
Try to find the hidden words given below.

N	Z	S	N	I	F	R	P	G	S	G	N	U	O	K
Z	O	A	I	R	S	A	C	U	X	R	O	Q	N	G
T	M	I	C	G	R	O	O	J	E	I	B	A	U	Q
J	L	U	T	A	M	G	M	N	K	G	R	A	U	X
Y	I	Q	F	U	O	A	A	E	O	N	A	E	P	S
U	L	F	G	L	T	K	B	Z	R	A	C	N	F	P
N	I	D	O	G	L	I	G	O	S	R	O	A	P	X
N	I	M	P	A	S	N	T	E	N	D	R	T	W	W
B	O	J	S	C	D	A	L	S	N	D	D	U	U	E
H	G	N	I	K	C	A	R	C	B	A	Y	B	R	H
C	A	P	U	I	U	A	N	W	X	U	H	E	T	A
P	E	T	R	O	L	E	U	M	T	C	S	T	Z	J
N	M	Q	N	K	C	A	R	B	O	N	V	L	E	J
V	S	L	Y	N	A	K	Y	R	Z	L	F	R	T	M
Z	C	L	W	W	Y	S	S	N	W	P	N	R	Z	C

ALKANE	HOMOLOGOUS	PETROLEUM
ALKYL	HYDROCARBON	SIGMABOND
BUTANE	ISOMER	SUBSTITUTION
CARBON	IUPAC	WURTZ
CRACKING	METHANE	
GRIGNARD	PARAFFIN	

FALLEN PHRASES (Methane)

Letters of the words are mixed in vertically. Place the letters in the correct box and get the message.



ALKENES

HYDROCARBONS

INTRODUCTION

Alkenes are unsaturated hydrocarbons whose structure contains $\rangle C{=}C \langle$ bonds. Each carbon atom having a carbon-carbon double bond has three σ (sigma) and one π (pi) bond. A double bond is formed because the carbon atoms don't bond to enough hydrogen atoms to complete their octet. For this reason, they are described as unsaturated. The carbon atoms joined by a double bond undergo sp^2 hybridization.

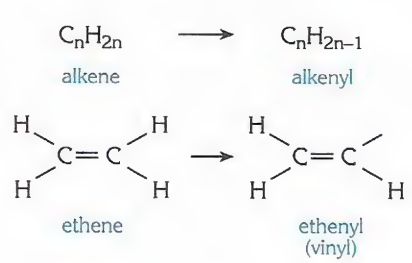
Alkenes are more reactive than alkanes because of the double bond in their structure. Alkenes are also known as olefins because they react with chlorine to form an oil-like liquid.

The general formula is C_nH_{2n} and the first member of this homologous series is C_2H_4. The systematic IUPAC name of this compound is ethene, though it is commonly known as is ethylene.

Alkenes containing two double bonds in their structures are called **alkadienes**; and ones having more than two double bonds are called **alkapolyenes**.

Name	Number of Carbon	Molecular Formula	Condensed Formula
Ethene	2	C_2H_4	$CH_2=CH_2$
Propene	3	C_3H_6	$CH_2=CHCH_3$
Butene	4	C_4H_8	$CH_2=CHCH_2CH_3$
Pentene	5	C_5H_{10}	$CH_2=CH(CH_2)_2CH_3$
Hexene	6	C_6H_{12}	$CH_2=CH(CH_2)_3CH_3$
Heptene	7	C_7H_{14}	$CH_2=CH(CH_2)_4CH_3$
Octene	8	C_8H_{16}	$CH_2=CH(CH_2)_5CH_3$
Nonene	9	C_9H_{18}	$CH_2=CH(CH_2)_6CH_3$
Decene	10	$C_{10}H_{20}$	$CH_2=CH(CH_2)_7CH_3$

Table 1 : *First nine members of the alkenes.*



1. ALKENYL GROUPS

When one hydrogen is removed from an alkene an alkenyl group is formed. The general formula of alkenyl groups is C_nH_{2n-1}. The most common alkenyls are ethenyl and propenyl. Some alkenyls are listed in Table 2.

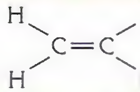
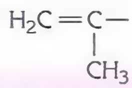
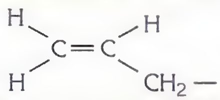
Alkenyl		Name	Common Name
	$H_2C{=}CH-$	Ethenyl	Vinyl
	$H_2C{=}\overset{\vert}{C}-CH_3$	Propenyl	Isopropenyl
	$H_2C{=}CHCH_2-$	Propenyl	Allyl

Table 2 : *Some alkenyl groups.*

Example 1

What is the molecular formula of the alkene of which 0.2 mole weighs 14 grams?

Solution

Let us find the molecular weight of the alkene.

$$M_{C_nH_{2n}} = \frac{m}{n} = \frac{14\ g}{0.2\ mole} = 70\ g/mol$$

The general formula of alkenes is C_nH_{2n}.

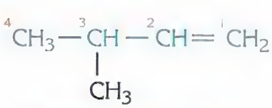
$12n + 2n = 70 \qquad 14n = 70 \qquad n = 5$

So, the molecular formula is : C_5H_{10}

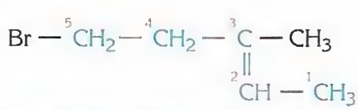
2. NOMENCLATURE OF ALKENES

First, the longest continuous carbon chain containing the double bond is chosen. Then the carbon atoms are numbered starting at the end nearest to the double bond. The location of the double bond is indicated by a number before the parent name of the alkene. Below are some examples:

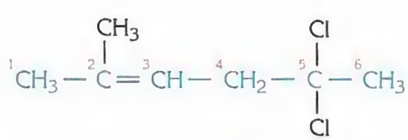
In the nomenclature of alkanes, we started to number the carbon atoms starting from the end nearest to the substituent. Note that when we are numbering the carbon atoms in alkenes, the double bond is more important.



3–methyl–1–butene



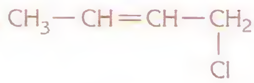
5–bromo–3–methyl–2–pentene

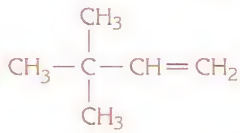


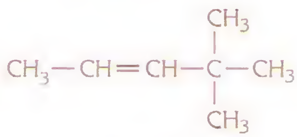
5,5–dichloro–2–methyl–2–hexene

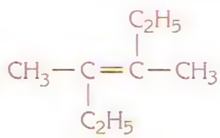
Example 2

Name the compounds below using the IUPAC system.

a. 

b. 

c. 

d. 

Solution

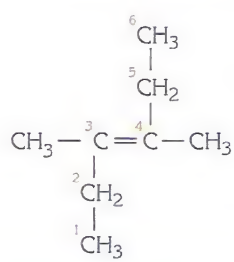
a. The parent name is 2–butene. If the numbering is started from the right, the Cl atom is attached to the first carbon. So, the name of the compound is *1–chloro–2–butene*.

b. The parent name is 1–butene. On the third carbon atom, two $-CH_3$ groups are attached. So, the name is *3,3–dimethyl–1–butene*.

c. The parent name is 2–pentene. Two methyl groups are attached to the fourth carbon atom. So, the name of the compound is *4,4–dimethyl–2–pentene*.

d. To choose the parent name the substituents ($-C_2H_5$) must be opened. Thus we get:

3,4–dimethyl–3–hexene.

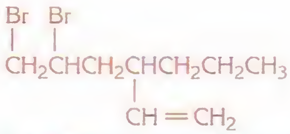


Example 3

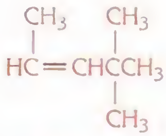
Which names of the following compounds are given correctly? Explain.

a. $CH_2{=}CH\ (CH_2)_5CH_3$

1–octene

b. 

6.7–dibromo–3–propyl–1–hexene

c. 

2.2–dimethyl–4–hexene

Solution

a. The compound is a straight chain alkene with eight carbon atoms. As the double bond is on the first carbon atom the name of the compound is 1–octene; so the given name is correct.

b. The longest continuous chain containing the double bond is made up of six carbon atoms. The double bond lies between the first and the second carbon atom so the compound is a 1–hexene. The substituents are a propyl group on the third carbon atom and two bromines on the fifth and sixth carbon atoms. So the name of the compound is 5,6–dibromo–3–propyl–1–hexene. The given name is incorrect.

c. If we start numbering the carbon atoms from the left hand side, the name of the compound comes out to be 4,4–dimethyl–2–pentene. The given name is incorrect.

Alkadienes and Polyenes

An alkene is a hydrocarbon which has only one double bond in its structure. Because of the one double bond, they are also called as monoalkenes. Alkenes having two double bonds in their structures are known as "**alkadienes**". While naming these, instead of the *–ene* suffix, *–diene* is used, and carbon atoms having the double bonds are indicated. Some examples of alkadienes and polyenes are shown as follows.

$^{1}CH_2={}^{2}CH-{}^{3}CH={}^{4}CH_2$
1,3–butadiene

$^{5}CH_3-{}^{4}CH={}^{3}CH-{}^{2}CH={}^{1}CH_2$
1,3–pentadiene

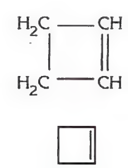
$CH_2=C=CH_2$
1,2–propadiene (allene)

$$\begin{array}{c} \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad Cl \\ \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad | \\ {}^{6}CH_2={}^{5}CH-{}^{4}CH_2-{}^{3}CH_2-{}^{2}C={}^{1}CH_2 \end{array}$$
2–chloro–1,5–hexadiene

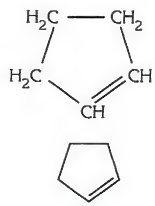
$$\begin{array}{c} \quad\quad\quad CH_3 \\ \quad\quad\quad | \\ {}^{1}CH_2={}^{2}C-{}^{3}CH={}^{4}CH_2 \end{array}$$
2–methyl–1,3–butadiene

If an alkene has three double bonds, it is named as shown below, and so on.

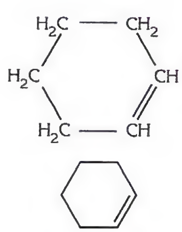
$^{1}CH_3-{}^{2}CH={}^{3}CH-{}^{4}CH={}^{5}CH-{}^{6}CH={}^{7}CH-{}^{8}CH_3$
2,4,6–octatriene



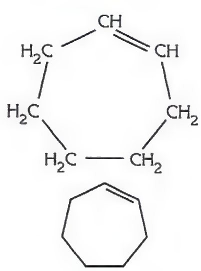
C_4H_6
cyclobutene



C_5H_8
cyclopentene



C_6H_{10}
cyclohexene



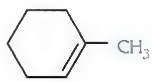
C_7H_{12}
cycloheptene

Some examples of cycloalkenes

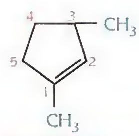
Cycloalkenes

Alkenes may have cyclic structures similar to alkanes. The first member of the cycloalkenes is cyclopropene.

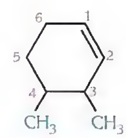
If there is a substituent attached to the ring the substituent is indicated at the front of the compound name.



1–methylcyclohexene

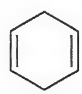


1,3–dimethylcyclopentene

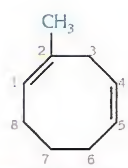


3,4–dimethylcyclohexene

Note that the carbon atoms of the double bond are always assigned as number 1 and 2.



1,4–cyclohexadiene



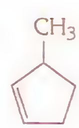
2–methyl–1,4–cyclooctadiene

Example 4

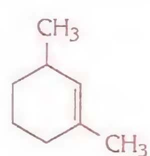
Name the given compounds using the IUPAC system.

a.
$$\begin{array}{l} CH_3C=CH_2 \\ \quad\;\; | \\ \quad CH_2CH_3 \end{array}$$

b.



c.



d. $CH_2=CH-CH_2-HC=CH-CH_3$

Solution

a. 2–methyl–1–butene

b. 3–methylcyclopentene

c. 1,3–dimethylcyclohexene

d. 1,4–hexadiene

3. ISOMERISM

For alkenes, in addition to structural isomerism, geometrical isomerism can also occur. Geometrical isomerism differs only in the arrangement of the atoms in space.

Structural Isomerism in Alkenes

In alkenes, as with alkanes, a difference in the carbon skeleton or the location of a substituent may cause isomerism. For example,

$$CH_2{=}CH{-}CH_2{-}CH_3 \qquad \begin{array}{c} \quad CH_3 \\ \quad | \\ CH_2{=}C{-}CH_3 \end{array}$$

1–butene   2–methylpropene

Additionally in alkenes, the C$=$C double bond may be between different carbon atoms in the carbon chain. This kind of arrangement would form a new compound with the same number of carbon and hydrogen atoms. In ethene and propene, there is only one possibility for the location of the C$=$C double bond. But in butene (C_4H_8) there are two possibilities;

$$CH_2{=}CH{-}CH_2{-}CH_3 \qquad CH_3{-}CH{=}CH{-}CH_3$$

C_4H_8 (1–butene) C_4H_8 (2–butene)

The only difference between 1–butene and 2–butene is the location of C$=$C double bond.

Both alkenes and cycloalkanes have the same general formula, C_nH_{2n}. Therefore every alkene, except C_2H_4, has a cycloalkane isomer. Cyclobutane, for instance, is isomeric with both the two structures drawn above.

$$\begin{array}{ccc} CH_2 & - & CH_2 \\ | & & | \\ CH_2 & - & CH_2 \end{array}$$

cyclobutane
(C_4H_8)

Structural isomers have the same molecular formula, but their structural formulae are different, and this leads to different physical and chemical properties. For example, C_5H_{10} has five isomers and all of them have different boiling points.

Alkadienes also have structural isomers as well as ordinary alkenes (Table 4).

Name	Molecular formula	Structural formula	Boiling Point (°C)
1-pentene	C_5H_{10}	$CH_3-CH_2-CH_2-CH=CH_2$	30
2-pentene	C_5H_{10}	$CH_3-CH_2-HC=CH-CH_3$	36.5
2-methyl-1-butene	C_5H_{10}	$CH_3-CH_2-\overset{CH_3}{\overset{\vert}{C}}=CH_2$	31.3
2-methyl-2-butene	C_5H_{10}	$CH_3-HC=\overset{CH_3}{\overset{\vert}{C}}-CH_3$	38.5
3-methyl-1-butene	C_5H_{10}	$CH_3-\overset{CH_3}{\overset{\vert}{CH}}-HC=CH_2$	20.15

Table 3 : *Some isomers of pentene*

Name	Molecular formula	Structural formula	Boiling point (°C)
1,2-pentadiene	C_5H_8	$CH_2=C=CH-CH_2-CH_3$	44.8
1,3-pentadiene	C_5H_8	$CH_2=CH-HC=HC-CH_3$	41
1,4-pentadiene	C_5H_8	$CH_2=CH-CH_2-HC=CH_2$	26
2,3-pentadiene	C_5H_8	$CH_3-HC=C=CH-CH_3$	48.2

Table 4 : *Some isomers of pentadiene*

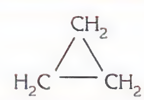
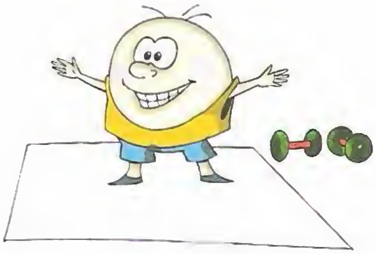
Name	Molecular formula	Structural formula	Boiling point (°C)
cyclopropane	C_3H_6		-33
propene	C_3H_6	$CH_2=\overset{H}{\overset{\vert}{C}}-\underset{\underset{H}{\vert}}{\overset{H}{\overset{\vert}{C}}}-H$	-48

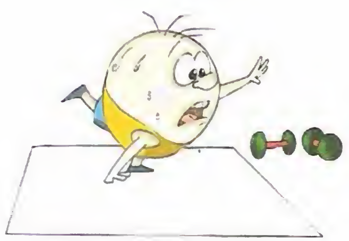
Table 5 : *Isomers of C_3H_6*

Cis-Trans Isomerism in Alkenes (Geometric Isomerism)

Cis-trans isomers differ from each other in the arrangement of their atoms in space. This type of isomerism occurs because the carbon-carbon double bond has a limited ability to rotate.



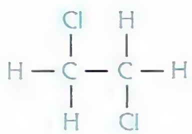
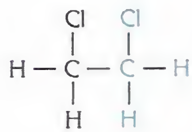
cis position



trans position

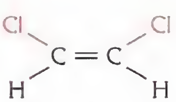
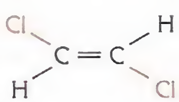
In alkanes (—C—C—) with single bonds, substituents attached to central carbon atoms are able to rotate freely.

So they don't have a fixed place in space. For example, in 1,2-dichloro ethane.

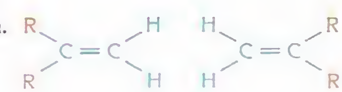
 and 

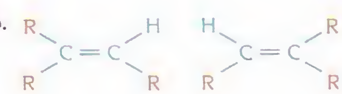
are not isomers of each other, they are identical.

In alkenes however, subitituents attached to the (—C=C—) carbon atoms cannot rotate freely. This structure can form two different compounds which have the same number and type of atoms, but a different geometrical order in space. This is called geometric or cis-trans isomerism. For example,

 and 

are different compounds. If the same groups are on the same side of the double bond, this is called the cis- isomer (in Latin, on the same side); if they are on opposite sides, it is called the trans- isomer (in Latin; cross-side). Cis-trans isomers have different physical properties.

a. 

b. 

In each pair above, given compounds do not exhibit cis-trans isomerism. If one molecule is turned 180° it can be seen they are actually the same molecule.

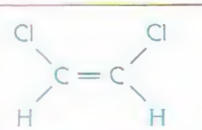
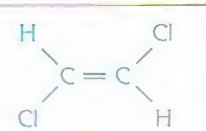
structural formula	 Cis-1,2-dichloroethene	 Trans-1,2-dichloroethene
molecular formula	$C_2H_2Cl_2$	$C_2H_2Cl_2$
melting point boiling point density (20°C)	-80.5°C 60°C 1.284 g/mL	-50°C 48°C 1.257 g/mL

Table 6 : *Geometric isomers (cis-trans) of $C_2H_2Cl_2$.*

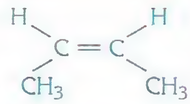
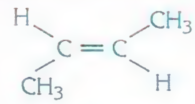
Structural formula	 Cis–2–butene	 Trans–2–butene
molecular formula	C_4H_8	C_4H_8
melting point boiling point density (20°C)	–139 °C 3.7 °C 0.621g/mL	–105 °C 0.88 °C 0.624 g/mL

Table 7 : ***Geometrical isomers (cis-trans) of 2–butene (C_4H_8)***

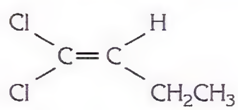
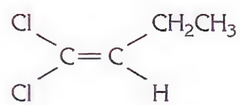
Example 5

Write the structural formulae of the given compounds and show if they have cis-trans isomerism.

a. 1,1–dichloro–1–butene, **b.** 1,2–dibromoethene, **c.** 3–hexene

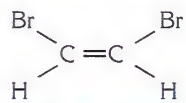
Solution

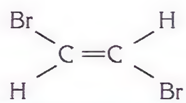
a. 1,1–dichloro–1–butene

 and 

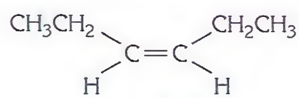
They are the same compounds. The two chlorine atoms are on the same carbon atom. Thus, there is no cis–trans isomerism in this compound;

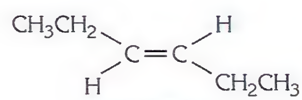
b. 1,2–dibromoethene can be written in two different ways, therefore it has cis– and trans– isomers.


cis–1,2– dibromoethene


trans–1,2– dibromoethene

c. 3–hexene can be written in two different ways, therefore it has cis–– and trans– isomers.


cis–3– hexene


trans–3– hexene

Name	Molecular Formula	Structural Formula	Melting Point (°C)	Boiling Point (°C)	Density (g/mL)
Ethene (Ethylene)	C_2H_4	$CH_2=CH_2$	–169.0	–104.0	0.384
Propene (Propylene)	C_3H_6	$CH_2=CHCH_3$	–185.2	–47.0	0.514
1-Butene	C_4H_8	$CH_2=CHCH_2CH_3$	–185.0	–6.3	0.595
1-Pentene	C_5H_{10}	$CH_2=CH(CH_2)_2CH_3$	–165.2	30.0	0.641
1-Hexene	C_6H_{12}	$CH_2=CH(CH_2)_3CH_3$	–138.0	63.5	0.673
1-Heptene	C_7H_{14}	$CH_2=CH(CH_2)_4CH_3$	–119.0	93.0	0.697
1-Octene	C_8H_{16}	$CH_2=CH(CH_2)_5CH_3$	–104.0	122.5	0.715
1-Nonene	C_9H_{18}	$CH_2=CH(CH_2)_6CH_3$	–81.3	146.8	0.729
1-Decene	$C_{10}H_{20}$	$CH_2=CH(CH_2)_7CH_3$	–87.3	170.5	0.741

Table 9 : *Physical properties of some alkenes*

4. PHYSICAL PROPERTIES OF ALKENES

The physical properties of alkenes are similar to those of alkanes. Alkenes which contain 2-4 carbon atoms are gaseous, 5-17 carbon atoms are liquids, and higher alkenes are solids at room temperature.

Boiling points increase as the number of carbon atoms increases. Branching is an important factor which decreases the boiling point of alkenes. The densities of alkenes are a little bigger than those of the same sized alkanes.

Hydrocarbon	B.P. (°C)	M.P (°C)
Ethane	– 88.6	– 183
Ethylene	– 103.8	– 169
Propane	– 42	– 187
Propylene	– 47	– 185.2
n–butane	– 0.5	– 138
1–butene	– 6.3	– 185
cis–2–butene	3.7	– 139
Trans–2–butene	1	– 106
n–Pentane	36.5	– 129
1–pentene	30.0	– 165
cis–2–pentene	37.9	– 151
Trans–2–pentene	36.4	– 140

Table 8 : *Boiling points and melting points of some hydrocarbons.*

5. CHEMICAL PROPERTIES AND REACTIONS OF ALKENES

The chemical properties of alkenes are very different from those of alkanes because of the double bond ($-C=C-$) in the structure. Double bond contains a sigma bond and a pi bond. Since electrons in pi bonds are bonded less strongly than in sigma bonds. This makes alkenes chemically reactive: combustion, substitution, oxidation and polymerization reactions are all undergone by alkenes.

5.1. COMBUSTION REACTIONS

Alkenes produce CO_2 and H_2O when they are burnt with a sufficient amount of oxygen. The general combustion reaction of alkenes is;

$$\boxed{C_nH_{2n} + \frac{3n}{2} O_2 \longrightarrow nCO_2 + nH_2O}$$

For example the combustion reaction of hexene is

$$C_6H_{12} + 9\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

In these reactions, the amount of energy released is less than that of the corresponding alkane.

Example 6

33.6 L oxygen is required to burn 0.25 mole of an alkene at STP. What is the molar mass of this alkene? (C:12; H:1)

Solution

$$C_nH_{2n} + (3n/2)\,O_2 \longrightarrow nCO_2 + nH_2O$$

$$n_{O_2} = \frac{V}{Vm} = \frac{33.6\ L}{22.4\ l/mol} = 1.5\ mol$$

1 mol alkene requires 3n/2 mol O_2

0.25 mol alkene requires 1.5 mol O_2

n = 4

The formula of the compound is C_4H_8 . The name of the compound is butene.

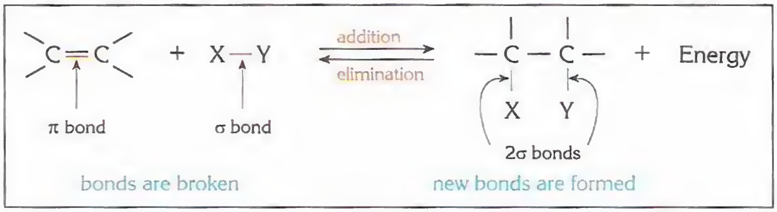
$$M_{(C_4H_8)} = (4 \cdot 12) + (8 \cdot 1) = 56\ g/mol$$

5.2. ADDITION REACTIONS

Addition reactions are characteristic of unsaturated compounds. In addition reactions, an unsaturated bond ($C{=}C$, $C{\equiv}C$, etc.) is completely or partially saturated by addition of a molecule across the multiple bond.

The most important addition reactions are the addition of hydrogen (H_2), the halogens (X_2), the hydrogen halides (HX) and water (H—OH).

In an addition reaction, one π bond and one σ bond are converted into two σ bonds. The heat released in the formation of two σ bonds is greater than that needed to break one σ bond and one π bond, therefore addition reactions are exothermic. The reverse of the addition reaction is known as elimination reaction.



Addition of Hydrogen

Ni, Pt or Pd metals are used as catalysts in addition reactions of hydrogen to alkenes.

Addition of H_2 to alkenes, which are unsaturated hydrocarbons, produces saturated hydrocarbons, i,e., alkanes.

Depending upon the number of double bonds, the moles of H_2 required for the reaction changes. If there is only one double bond, one mole of hydrogen is needed per mole of alkene. If there are two double bonds, two moles of hydrogen molecules are needed.

$$\underset{\text{alkene}}{C_nH_{2n}} + H_2 \xrightarrow{\text{Ni. Pt}} \underset{\text{alkane}}{C_nH_{2n+2}}$$

$$\underset{\text{ethylene}}{CH_2{=}CH_2} + H_2 \xrightarrow{\text{Ni. Pt}} \underset{\text{ethane}}{\begin{array}{cc} CH_2 - & CH_2 \\ | & | \\ H & H \end{array}}$$

$$\underset{\text{1.2-butadiene}}{CH_2{=}C{=}CH-CH_3} + 2H_2 \xrightarrow{\text{Ni. Pt}} \underset{\text{butane}}{CH_3-CH_2-CH_2-CH_3}$$

Addition of Halogens

Halogens may be added to alkenes at room temperature without a catalyst. One mole of alkene requires one mole of halogen.

$$R-CH{=}CH_2 + X_2 \xrightarrow{25\ C} \underset{\text{dihaloalkane}}{\begin{array}{ccc} R- & CH- & CH_2 \\ & | & | \\ & X & X \end{array}}$$

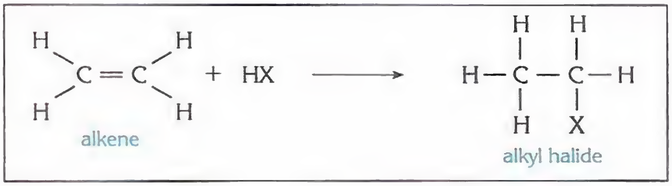
$$\underset{\text{2-butene}}{CH_3-CH{=}CH-CH_3} + Br_2 \xrightarrow{25\ C} \underset{\text{2.3-dibromobutane}}{\begin{array}{cccc} CH_3- & CH- & CH- & CH_3 \\ & | & | & \\ & Br & Br & \end{array}}$$

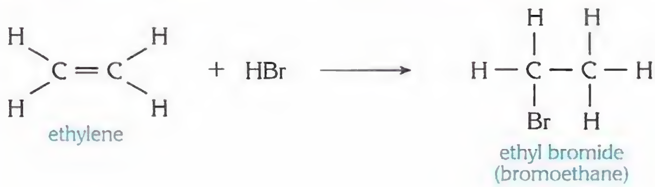
Addition of Br_2 to alkenes is a useful reaction which shows us if a hydrocarbon is saturated or unsaturated. When an unknown hydrocarbon is added to a solution of Br_2 in water, if the color of solution disappears, it is an unsaturated hydrocarbon (alkene or alkyne). If color doesn't change, it is an alkane.

When an unsaturated hydrocarbon is added to a solution of bromine (tube on the left), it becomes colorless (tube on the right).

Addition of Hydrogen Halides

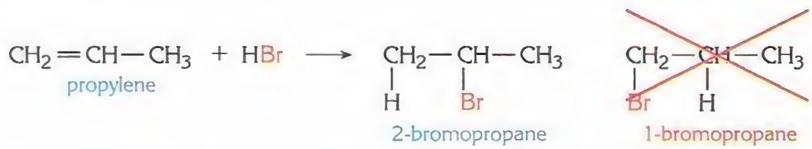
Hydrogen halides, (HCl, HBr) may be added easily to the double bond of alkenes.



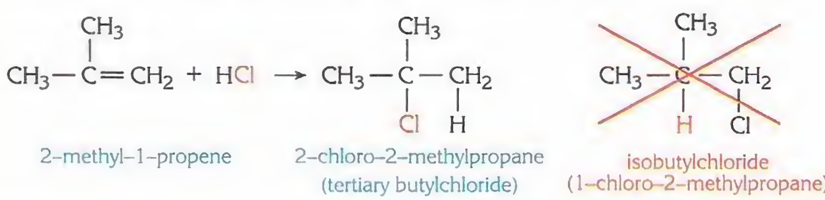


In this reaction the carbon atoms to which hydrogen and bromine atoms are attached are not important, there is only one possible product.

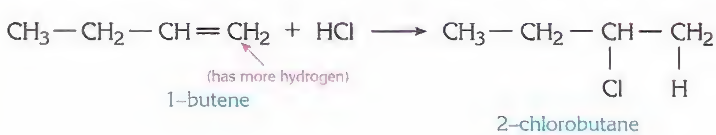
Addition of hydrogen halides to unsymmetrical alkenes on the other hand, may form two possible products. However, only one of these products usually predominates.



As it is seen in the above example, for the addition of HBr to an unsymmetrical alkene, hydrogen attaches to the carbon atom that has the greater number of hydrogen atoms. This is known as **Markovnikov's** rule.



According to Markovnikov's rule; addition of HCl to 1-butene gives 2-chlorobutane.



THE PIONEERS

Markovnikov,
Vladimir Vasilyevich
(1838-1904)

Markovnikov was a Russian chemist. He studied at Kazan University under Butlerov and later came back to teach there. In 1869 while studying addition reactions, he noticed a trend in the structure of the favored product.

This trend is now called the Markovnikov's Rule and it states that in the addition of HX to an alkene, hydrogen adds to the carbon with the most hydrogen atoms. This rule is a very useful aid for predicting experimental results.

Markovnikov also studied the composition of petroleum hydrocarbons. He became a professor at Moscow University in 1873.

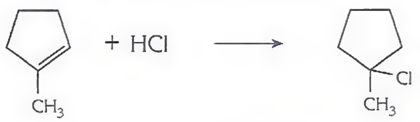
Example 7

Complete the following equation

1–methylcyclopentene

Solution

According to Markovnikov's rule; hydrogen attaches to the carbon atom that has the greater number of hydrogen atoms. Thus;

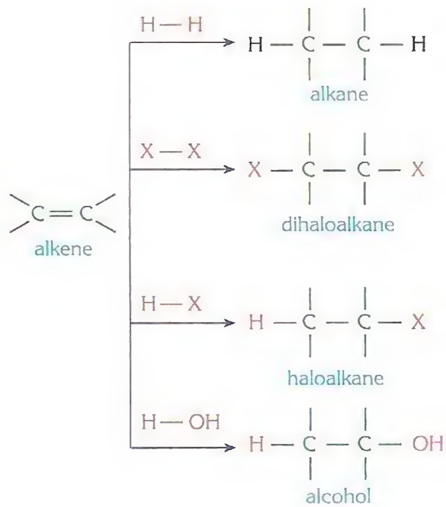


1–chloro–1–methylcyclopentane

Addition of Water

Addition of water (H—OH) to alkenes also occurs according to Markovnikov's rule. Hydrogen (—H) of water is added to the carbon atom of the double bond that already has the greater number of hydrogen atoms. —OH is added to the carbon atom of the double bond that has the smaller number of hydrogen atoms. In this reaction, H_2SO_4 is used as catalyst, and a monoalcohol is produced.

$$\underset{\text{Propene}}{CH_3-CH=CH-H} + HOH \xrightarrow{H_2SO_4} \underset{\substack{\text{2 – hydroxy propane} \\ \text{(isopropyl alcohol)}}}{CH_3-\underset{OH}{\underset{|}{CH}}-\underset{H}{\underset{|}{CH}}-H}$$



Addition of H_2, X_2, HX and H_2O to an alkene.

Example 8

Complete the equations and write the names of products.

a. 1–butene + H_2 $\xrightarrow{Pt}$

b. butane + H_2 $\xrightarrow{Pt}$

c. 1–methyl cyclohexene + Cl_2 $\longrightarrow$

d. propene + HCl $\longrightarrow$

e. 1–pentene + H_2O $\xrightarrow{H_2SO_4}$

Solution

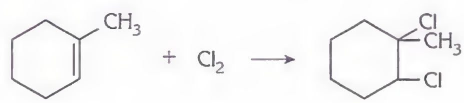
a. 1–butene + H_2 $\xrightarrow{Ni}$ butane

$CH_2{=}CHCH_2CH_3{+}H_2 \xrightarrow{Ni} CH_3{-}CH_2CH_2CH_3$

b. Butane + H_2 $\xrightarrow{Pt}$ no reaction.

Butane is a saturated hydrocarbon, so it doesn't undergo addition reactions.

c. 1–methylcyclohexene + Cl_2 $\longrightarrow$ 1,2 dichloro–1–methylcyclohexene



d. propene + HCl $\longrightarrow$ 2–chloropropane

$$CH_2{=}CH{-}CH_3{+}HCl \longrightarrow CH_3{-}\underset{}{\overset{\overset{\displaystyle Cl}{|}}{CH}}{-}CH_3$$

e. 1–pentene + H_2O $\xrightarrow{H_2SO_4}$ 2–pentanol

$$CH_2{=}CHCH_2CH_2CH_3{+}H_2O \longrightarrow CH_3{-}\overset{\overset{\displaystyle OH}{|}}{CH}\,CH_2\,CH_2\,CH_3$$

Example 9

2 moles of a mixture methane (CH_4) and ethylene (C_2H_4) react completely with 32 grams of Br_2. What is the mole percentage of methane in the mixture?

(M_{Br} : 80 g/mol)

Solution

Let's first find the number of moles of bromine (Br_2).

$$n_{Br_2} = \frac{32}{160\ g/mol} = 0.2\ mole$$

CH_4 is a saturated hydrocarbon. Thus, only C_2H_4 reacts with Br_2 in an addition reaction.

$C_2H_4{+}Br_2 \longrightarrow C_2H_4Br_2$

1 mol Br_2	1 mol ethene
0.2 mol Br_2	x mol ethene

$n_{C_2H_4} = 0,2$ mole

Now we can calculate the mole percentage of methane (X_{CH_4})

$$X_{CH_4} = \frac{1.8}{2} \cdot 100 = 90\%$$

5.3. OXIDATION REACTIONS

Alkenes undergo oxidation reactions in which the carbons in the double bond are oxidized.

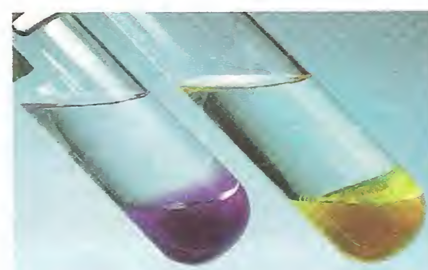
Cleavage of the π bond (Baeyer Method)

Alkenes give diols after oxidation by cold, dilute $KMnO_4$ solution. π bonds are broken but σ bonds are not affected by this oxidation.

This reaction can be used to confirm whether or not a compound is an alkene. When an alkene is treated with cold, alkaline $KMnO_4$ solution, the violet color of $KMnO_4$ solution disappears and turns brown. This is called Baeyer's reaction.

$$3\ \underset{\text{ethene}}{H_2C{=}CH_2} + \underset{\text{violet}}{2KMnO_4} + 4H_2O \xrightarrow[\text{alkaline}]{\text{cold}} 3\ \underset{\substack{\text{1,2 ethandiol}\\ \text{(ethylene glycol)}}}{H-\underset{OH}{\overset{H}{C}}-\underset{OH}{\overset{H}{C}}-H} + \underset{\text{brown}}{2MnO_2\downarrow} + 2KOH$$

Reaction of ethene with $KMnO_4$ and the formation of brown MnO_2 solution.



To distinguish between alkanes and alkenes, $KMnO_4$, an oxidising agent in a basic solution is used.

5.4. POLYMERIZATION

A **polymer** is a long, repeating chain of atoms, formed through the linkage of many identical molecules called **monomers**. The reaction by which polymers are formed is called polymerization.

$$n\ \underset{\substack{\text{ethylene}\\ \text{(monomer)}}}{CH_2{=}CH_2} \xrightarrow{\text{heat}} \underset{\substack{\text{polyethylene}\\ \text{(Polymer)}}}{(-CH_2-CH_2-)_n}$$

6. POLYMERS

Polymers consist of very large molecules that are made up of many repeating smaller molecules.


Polymers have a wide usage.

Proteins, nucleic acids, starch, cellulose, silk and natural rubber are the most widely encountered natural polymers. These natural polymers can be imitated in laboratories and synthetic polymers produced.

80% of organic chemistry is related to polymer chemistry. One of the simplest polymers is polyethylene which is made from many ethylene molecules. Trash bags, sandwich wraps, teflon, automobile tyres, varnishes and paints are all examples of polymers that we use in our daily life.

Because of the huge size of polymer molecules, the van der Waals forces between the molecules are very strong. Thus, their boiling and melting points are very high in comparison to their monomers. They are hard, strong and have a wide usage.

Synthetic polymers are grouped into two categories: addition polymers and condensation polymers. A **condensation polymerization** occurs when a polymer is formed by a reaction that leaves behind a small molecule, such as water.

Alkenes undergo addition polymerization. **Addition polymerizations** are reactions where a polymer is formed from its monomers with no other molecules produced. Polyethylene is an addition polymer; each unit adds to the chain without leaving any residue behind.


Automobile tyres are made up of polymers.


Some goods made up of polymers.

6.1. POLYETHYLENE

Ethylene polymerizes by a radical mechanism when it is heated at a pressure of 1000-3000 atm at 250°C with a small amount of an organic peroxide. The properties of polyethylene may change according to the reaction conditions.

Polyethylene is the most widely used of all plastics because it is inexpensive, flexible, extremely tough, and chemically resistant.

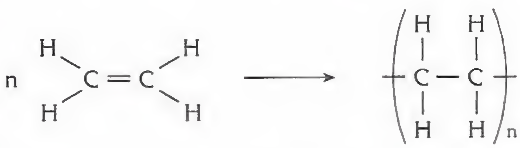
High density polyethylene, HDPE, is used for grocery bags, car fuel tanks, packaging and piping.

Low density polyethylene, LDPE, is softer and more flexible than HDPE. LDPE is used for bottles, garment tags, frozen food packs, film and plastic toys.

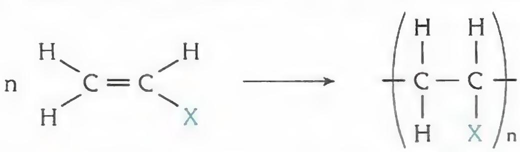
Plastic bottles made up of both high density polyethylene left and low density polyethylene right.

6.2. POLYMERS OF SOME ETHYLENE DERIVATIVES

We know that ethylene is polymerized according to the reaction;



If ethylene undergoes a substitution reaction before polymerization, a new derivative of ethylene may be polymerized. This can be shown by the general formula;

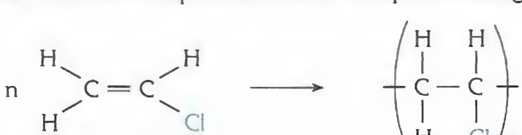


Here, X may donate a halogen (Cl, F), alkyl or another functional group (—OH, NH_2, etc)

Raw material of polyethylene

Polyvinyl chloride (PVC)

If one hydrogen is replaced with chlorine in the ethylene molecule, vinyl chloride is formed. If vinyl chloride polymerizes polyvinyl chloride, known as PVC, is formed. PVC is lightweight, long lasting, and waterproof. In its rigid form, PVC is water-resistant and can be drawn out into pipes, house siding and drainpipes. It is also used in compact discs and computer casings.



vinyl chloride

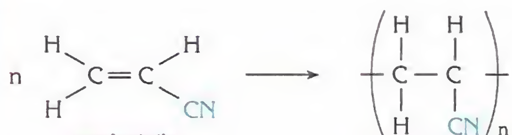
polyvinyl chloride (PVC)

Some products of PVC

Polyacrylonitrile

Orlon

If one hydrogen is replaced by —CN in the ethylene molecule, acrylonitrile is produced. When this compound polymerizes, polyacrylonitrile is produced. This is also known as orlon. It is used in synthetic fibers and rugs.



acrylonitrile

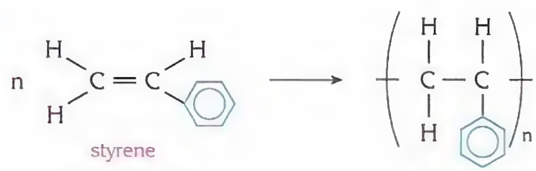
polyacrylonitrile

Polystyrene

Polystyrene

If one hydrogen in ethylene is replaced by a phenyl group, the compound styrene is produced. Styrene is polymerized to polystyrene.

Polystyrene is an amorphous, white and brittle plastic. Polystyrene has many applications due to its rigidity. Polystyrene is used for making products such as toys, display boxes, packaging material, egg cartons and styrofoam.



styrene

polystyrene

Polytetrafluoroethylene (Teflon)

If all the hydrogen atoms in ethylene are replaced by fluorine atoms, tetrafluoro ethylene results. Tetrafluoroethylene is polymerized to form polytetrafluoro ethylene. Polytetrafluoroethylene, known as teflon, is used in the production of nonstick cooking ware.

Teflon pan

tetrafluoroethylene

polytetrafluoroethylene (Teflon)

Polypropylene

The second member of alkenes, propylene, can also be polymerized under suitable conditions. Polypropylene is used in the production of bottles, electric battery cases and rugs.

Polypropylene

propylene

polypropylene

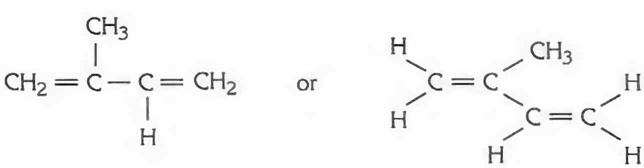
6.3. POLYMERS OF BUTADIENE DERIVATIVES

The derivatives of butadiene are natural rubber and synthetic rubber.

Natural Rubber

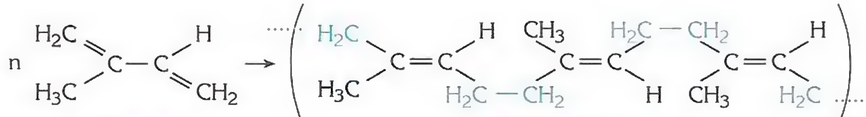
Raw materials of butadiene

Natural rubber is extracted from the hevea brasiliensis tree which is grown in tropical regions. When its bark is slit with a cutter, a liquid, named latex, is obtained. Latex is an emulsion of rubber in water. When acid is added to this emulsion, natural rubber is precipitated. This precipitate is the polymer of a hydrocarbon with the molecular formula C_5H_8



The common name of this compound is isoprene and its IUPAC name is 2–methyl–1,3–butadiene. Polymerization of isoprene gives polyisoprene, natural rubber. Polymerization may lead to cis or trans versions of polyisoprene.

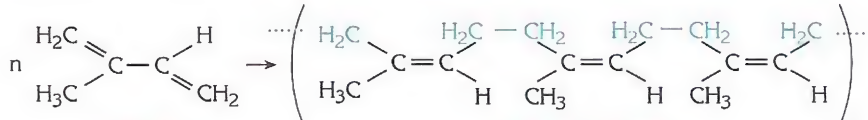
Latex tree



isoprene

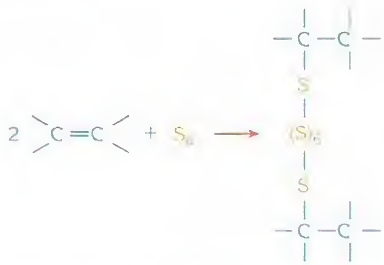
Poly–trans–isoprene
(Trans–1,4–polyisoprene)

The trans–isomer is stiffer than the cis-polymer and used in the production of golf balls, golf clubs, and tennis-rackets.



isoprene

Poly–cis–isoprene
(Cis–1,4–polyisoprene)



S_8 is added to the double bond of the alkene in the vulcanization process.

Natural rubber with its natural structure is a sticky substance with low elasticity which isn't very useful to the chemical industry. However, when natural rubber is heated with sulfur, it becames harder, less soluble and more durable and so much more useful. This process is known as **vulcanization**.

In 1839, Charles Goodyear (1800-1860) vulcanized rubber by heating natural rubber with sulfur. Instead of a low-elastic, sticky product being formed, a more elastic and stronger polymer was formed. According to the percentage of added sulfur, the properties of the rubber vary.

If the percentage of sulfur is 1-5%, a soft rubber is produced. Soft rubber is used in the production of shoe soles, car inner tubes, plastic gloves and many more different products. The rubber used in car tyres is produced if the proportion of sulphur is 30-50%.

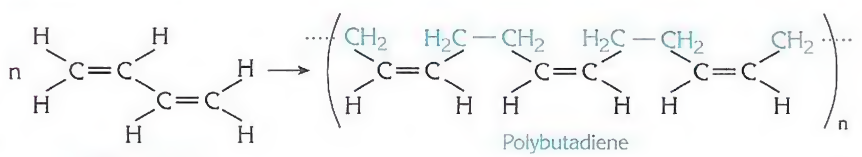
A vulcanized product of rubber

Synthetic rubber

After the usage of natural rubber became widespread, scientists started to investigate the production of synthetic rubber.

In 1920, a German chemist produced an artificial rubber by polymerizing butadiene obtained from petroleum. This rubber was named BuNa rubber (Bu from butadiene and Na from the sodium which was used as the catalyst in the reaction)

Synthetic rubber is flexible



1,3–butadiene

Polybutadiene

After the production of polybutadiene, the automotive industry developed very rapidly. Car tyres, interior and exterior parts of cars could now be produced from artificial rubber.

READING POPULAR SPORTS AND POLYMERS


Mountain climbing


Parachute


Snowboard


tennis balls and racket


Rollerskate


Bicycle

Polymers opened a new age in the production of rubbers and plastics. Today we use many hundreds of products produced by polymerization reactions. Many sports have been improved with help of polymers and consequently these sports have become more popular than ever. For example, skiers and mountain climbers today have a great advantage over their counterparts of yesteryear.

Equipment used for skiing and snowboarding have become much more lighter and ergonomic. The bottom of skies are waxed to decrease friction. In mountain climbing, tools are now made very strong, light and resistant to the natural elements such as wind, sun and the rain.

In cycling, light polymer products have replaced metal parts. Today's bicycles are more efficient than those used previously because of their improved strength and resistance. Also, polymer helmets are lighter and stronger than ever before.


Rafting


hi-tech sport shoes


bungee jumping

Car tyres are produced while using synthetic rubber

7. PREPARATION OF ALKENES

7.1. DEHYDRATION OF MONOALCOHOLS

Dehydration is the removal of water from a compound. Heating most alcohols with a strong acid causes them to lose a molecule of water and form an alkene. This process is called the dehydration of alcohols.

$$\underset{\text{alcohol}}{R-CH_2-CH_2-OH} \xrightarrow[150^\circ C]{\text{concentrated } H_2SO_4} \underset{\text{alkene}}{R-CH=CH_2} + H_2O$$

$$\underset{\text{isopropyl alcohol}}{\underset{\underset{H}{|}}{CH_2}-\underset{\underset{OH}{|}}{CH}-CH_3} \xrightarrow[150^\circ C]{\text{concentrated } H_2SO_4} \underset{\text{propene}}{CH_2=CH-CH_3} + H_2O$$

7.2. DEHYDROHALOGENATION OF ALKYL HALIDES

When alkyl halides are treated with KOH in an alcohol solution at high temperatures, alkenes are produced. Such reactions in which a hydrogen halide is removed from the compound are called dehydrohalogenation reactions.

$$\underset{\text{alkyl halide}}{R-\underset{\underset{H}{|}}{CH}-\underset{\underset{X}{|}}{CH_2}} + KOH \xrightarrow{C_2H_5OH} \underset{\text{alkene}}{R-CH=CH_2} + KX + H_2O$$

$$\underset{\text{propyl bromide}}{CH_3-CH_2-CH_2-Br} + KOH \xrightarrow{C_2H_5OH} \underset{\text{propene}}{CH_3-CH=CH_2} + KBr + H_2O$$

7.3. DEHYDROGENATION OF ALKANES

At high temperatures (800° C) and with the catalyst Al_2O_3, alkanes form alkenes by losing two hydrogen atoms from two adjacent carbon atoms

$$\underset{\text{alkane}}{R-CH_2-CH_3} \xrightarrow[800^\circ C]{Al_2O_3} \underset{\text{alkene}}{R-CH=CH_2} + H_2$$

$$\underset{\text{ethane}}{CH_3-CH_3} \xrightarrow[800^\circ C]{Al_2O_3} \underset{\text{ethylene}}{CH_2=CH_2} + H_2$$

7.4. CRACKING OF ALKANES

When long-chained alkanes are heated at high temperature they decompose to produce a simpler alkane and an alkene.

$$\underset{}{C_{16}H_{34}} \xrightarrow[\text{heat}]{\text{catalyst}} \underset{\text{octane}}{C_8H_{18}} + \underset{\text{octene}}{C_8H_{16}}$$

7.5. DEHALOGENATION OF DIBROMIDES

When alkyl halides with two bromine atoms on adjacent carbon atoms are reduced with Zn metal in acidic solution, alkenes are formed.

$$\boxed{-\underset{\text{Br}}{\underset{|}{\overset{|}{C}}}-\underset{\text{Br}}{\underset{|}{\overset{|}{C}}}- \xrightarrow[\text{acid}]{\text{Zn}} {>}C=C{<} \; + \; ZnBr_2}$$

$$\underset{\text{Br}}{\underset{|}{CH_2}}-\underset{\text{Br}}{\underset{|}{CH}}-CH_3 + Zn \longrightarrow CH_2=CH-CH_3 + ZnBr_2$$

8. ETHYLENE

Ethylene is the simplest alkene. It is a colorless gas with a specific odor, it is slightly soluble in water but dissolves very well in organic solvents. The density of ethylene is similar to that of air.

Ethylene is a very important gas which is used to manufacture many things we use in all aspects of life. The uses of this gas have been studied in the polymerization section.

Ethylene can be produced from coal gas and petroleum by cracking methods.

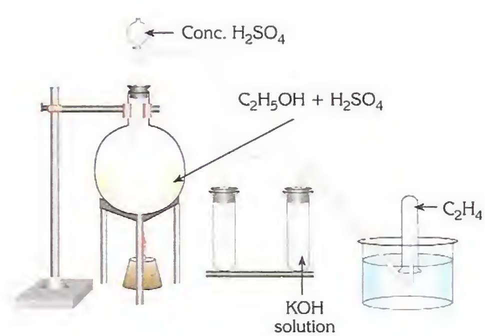
Ethylene shows all the chemical properties of alkenes. It undergoes combustion, addition reactions and polymerization reactions. It burns with a bright yellow flame.

Preparation of Ethylene

Ethylene can be produced by any preparation method for alkenes.

a. By heating one mole of ethyl alcohol with an acid catalyst (H_2SO_4) 1 mol of water is eliminated. The reaction is carried out between 150–170°C.

$$\underset{\text{ethyl alcohol}}{C_2H_5OH} \xrightarrow[150^\circ - 170^\circ C]{\text{conc. } H_2SO_4} \underset{\text{ethylene}}{\overset{H \qquad H}{\underset{H \qquad H}{C=C}}} + H_2O$$



Preparation of ethylene from ethyl alcohol.

b. When ethyne (C_2H_2) is hydrogenated with the catalyst palladium (Pd), calcium carbonate ($CaCO_3$) and lead (II) acetate ($Pb(CH_3COO)_2$), ethylene is obtained. The reaction does not continue because the catalyst inhibits further reaction.

$$\underset{\text{acetylene}}{C_2H_2} + H_2 \xrightarrow[\text{heat}]{\text{catalyst}} \underset{\text{ethylene}}{C_2H_4}$$

Example 10

Ethylene is produced from 9.2 grams of ethyl alcohol (C_2H_5OH)

a. How many moles of ethylene are produced?

b. How many liters of H_2 gas are required to saturate the ethylene produced at STP?

(C_2H_5OH : 46)

Solution

a. Let's first write the equation of the reaction:

$$C_2H_5OH \xrightarrow[\text{heat}]{H_2SO_4} C_2H_4 + H_2O \Rightarrow$$

We can find the number of moles of ethanol:

$$n_{C_2H_5OH} = \frac{m}{M} = \frac{9.2\text{ g}}{46\text{ g/mol}} = 0.2\text{ mole}$$

0,2 mol of alcohol produces 0.2 mol C_2H_4 as the ratio between the mole numbers of ethylene and alcohol is 1 to 1.

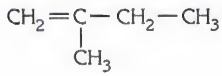
b. $C_2H_4 + H_2 \longrightarrow C_2H_6$

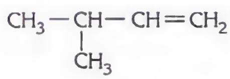
1 mol ethylene requires	22.4 L H_2 at S.T.P.
0.2 mol ethylene requires	x

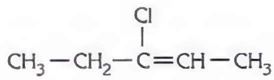
$V_{H_2} = x = 4.48$ L

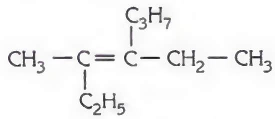
SUPPLEMENTARY QUESTIONS

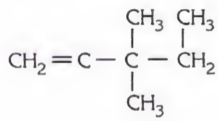
1. Give the IUPAC names of the following compounds.

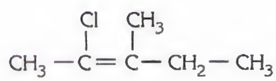
a. 

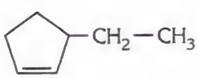
b. 

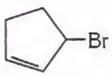
c. 

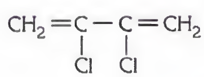
d. 

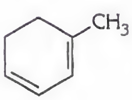
e. 

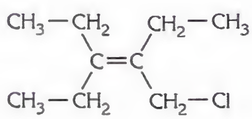
f. 

g. 

h. 

i. 

j. 

k. 

2. Write the structural formulae for the following compounds.
   a. 1,2 - dichloroethene
   b. 2,3 - dimethyl - 2 - pentene
   c. 1,3 - dibromocyclohexene
   d. cis - 3,4 - dibromo - 3 - hexene
   e. 1,3 - pentadiene
   f. 2 - bromo - 3 - methyl - 3 - hexene
   g. 3,5 - divinylcyclopentene
   h. 2,3 - dimethyl - 2 - butene
   i. 4 - ethyl - 3 - methyl - 3 - octene
   j. 3 - bromocyclopentene
   k. 2, 3, 4 - trimethyl - 4 - bromo - 2 - hexene
   l. 2 - chloro - 1,3 - butadiene

3. Draw the structural formulae of four of the isomers of C_6H_{12}. Name all the compounds.

4. Find the molecular formula of the cycloalkene that contains 10% hydrogen by mass.

5. The density of a gaseous alkene is 2.5 g/L at STP. Find its molecular formula.

6. Write the equations for the reactions between propene and the given substances. Name the products.
   a. H_2 b. Br_2 c. HBr d. H_2O

7. 5.6 L H_2 at STP is used to saturate a mixture of C_2H_4 and C_3H_6. When the products are burned 13.44 liters of CO_2 is released at STP. What is the mass percentage of ethylene in the original mixture?

8. At STP 4.48 liters of H_2 is needed to saturate 1 mole of a mixture of ethane and propene. What is the mass of ethane in the mixture?

9. How many grams of HCl solution which is 73% by mass are needed to saturate 16.8 liters of propene at STP?

10. Ethylene gas obtained from 40 grams ethyl alcohol solution is saturated with 200 grams of Br_2 solution, 5.6% by mass. What is the percentage purity of the ethyl alcohol solution?

(C : 12, H : 1, O : 16, Br : 80)

11. Explain Markovnikov's rule and complete the reactions below.

a. 1 – butene + HCl $\rightarrow$

b. 2 – methyl – 2 – pentene + HBr $\rightarrow$

c. 2 – chloro – 2 – butene + HI $\rightarrow$

d. 4 – bromo – 3 – heptene + H_2O $\rightarrow$

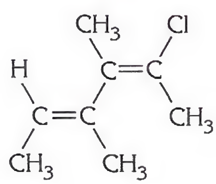
12. Complete the reactions below and name the products.

a. $C_3H_6 + O_{2(excess)} \longrightarrow$

b.  $+ O_{2(excess)} \longrightarrow$

c. $CH_3-CH=CH_2 + HCl \longrightarrow$

d. $CH_3-\underset{\underset{\displaystyle CH_3}{|}}{C}=CH_2 + Cl_2 \longrightarrow$

e.  $+ 2Br_2 \longrightarrow$

f. $CH_2=\underset{\underset{\displaystyle CH_3}{|}}{C}-CH=CH_2 + 2H_2O \longrightarrow$

g. $C_2H_4 + KMnO_4 + H_2O \longrightarrow$

13. Write the molecular formulae of the given compounds.

a. tetrafluoroethylene b. acrylonitrile

c. styrene d. vinyl chloride

e. isobutene f. isopyrene

14. Explain polymerization. Write the equation that represents the polymerization of vinyl chloride.

15. Write the names and molecular formulae of the alkenes obtained by the dehydration of the following alcohols with a H_2SO_4 catalyst.

a. CH_3-CH_2-OH

b. $CH_3-CH_2-\underset{\underset{\displaystyle OH}{|}}{CH}-CH_3$

c. $CH_3-\underset{\underset{\displaystyle CH_3}{|}}{CH}-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}-OH$

d. $CH_2-\underset{\underset{\displaystyle OH}{|}}{CH}-CH_3$

16. Complete the following equations:

a. $CH_3CH_2CH_2CH_2Cl + KOH \xrightarrow{\text{ethyl alcohol}}$

b. $CH_3CH_2\underset{\underset{\displaystyle Br}{|}}{C}HCH_2CH_3 + KOH \xrightarrow{\text{ethyl alcohol}}$

c.  $+ KOH \xrightarrow{\text{ethyl alcohol}}$

d. $CH_3-CH_2-CH_3 \xrightarrow[800\ °C]{Al_2O_3}$

17. Write out the preparation reactions of ethylene.

18. From 23 grams of ethyl alcohol (CH_3CH_2OH);

a. How many grams of ethylene can be obtained from a reaction having a 70% yield?

b. How many grams of 40% Br_2 solution is needed to saturate obtained ethylene?

MULTIPLE CHOICE QUESTIONS

1. What is the molecular formula of an alkene of which 0.3 mol weighs 21 grams? (C : 12, H : 1)

   A) C_2H_2 B) C_3H_6 C) C_4H_8 D) C_5H_{10} E) C_6H_{12}

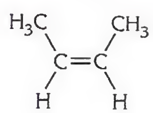
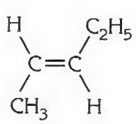
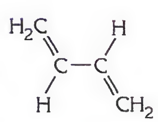
2. How many σ bonds are there in an alkene whose molecular weight is 56 grams?

   A) 10 B) 11 C) 12 D) 13 E) 14

3. A mixture containing equal moles of C_2H_4 and C_3H_8 contains 3.6 grams of hydrogen. What is the mass of carbon in the mixture?

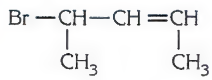
   A) 6 B) 9 C) 12 D) 18 E) 24

4.

	Compound	Name
I.		trans – 2 – butene
II.		cis – 2 – pentene
III.		1,3 – butadiene

   Which of the given compounds is/are named correctly?

   A) I only B) III only C) I and II D) II and III E) I and III

5. 

   What is the correct name of the compound?

   A) 1-bromo-1,3-dimethylpropene
   B) 1-bromo-1-methyl-3-butene
   C) 4-bromo-4-methyl-butene
   D) 4-bromo-2-pentene
   E) 2-bromo-4-pentene

6. All of the followings are isomers of each other except:

   A) Cyclohexane B) 2-hexene C) 3-methyl-1-pentene D) 1,3-hexadiene E) 3,3-dimethyl-1-butene

7. For $CH_2=CH-CH=CH_2$

   I. Its name is 1,4-butadiene.
   II. 1 molecule contains 9 σ and 2 π bonds.
   III. It is an isomer of 1-butyne.

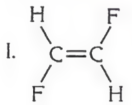
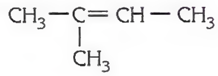
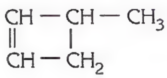
   Which of the above statements is/are correct?

   A) I only B) II only C) I and II D) I and III E) II and III

8. In which one of the following compounds is cis-trans isomerism observed?

   A) $CH_2=CH_2$
   B) $CH_3-CH=CH_2$
   C) $CH_2=CH-CH_2-CH_3$
   D) $CH_3-CH=CH-CH_3$
   E) $CH_3-CH_2-CH_2-CH=CH_2$

9.

Formula	Name
I. 	trans – 1,2 – difluoroethene
II. 	2 – methyl – 2 – butene
III. 	2 – methylcyclobutene

Which of the above is/are named correctly?

A) I only B) II only C) I and II

D) II and III E) I, II and III

10. Which one of the given aliphatic compounds undergoes an addition reaction with H_2 in the presence of Pt catalyst?

A) CH_4 B) C_2H_6 C) $C_2H_4Cl_2$

D) C_2H_5OH E) C_3H_6

11. In the saturation of 1 mole of acetylene with H_2:

I. 2 moles of π bonds are broken.

II. 4 moles of σ bonds are formed.

III. Ethane is formed.

Which of the above occur?

A) I only B) II only C) I and II

D) I and III E) I, II and III

12. All of the following hydrocarbons undergo addition reactions except for;

A) CH_4 B) C_2H_2 C) C_2H_4 D) C_3H_4 E) C_3H_6

13. 27 grams of a straight chained hydrocarbon containing two π bonds in its structure is fully saturated with 2 grams of hydrogen.

How many hydrogen atoms are there in one molecule of this compound?

A) 4 B) 5 C) 6 D) 8 E) 10

14. What is the name of the compound that is formed by the addition reaction between HBr and 2-bromo -2-butene?

A) 1,2-dibromobutane

B) 2,3-dibromobutane

C) 2,2-dibromobutene

D) 1,3-dibromobutane

E) 2,2-dibromobutane

15. Regarding the compound that is formed by the addition of HBr to 1-methylcyclopentene;

I. It is aliphatic.

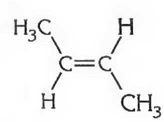
II. Its molecular formula is $C_6H_{13}Br$.

III. It is named as 1-bromo-1-methylcyclopentane.

Which of the above statements is/are wrong?

A) I only B) II only C) I and II

D) I and III E) I, II and III

16. 

For the above compound;

I. It is named as trans-2-butene.

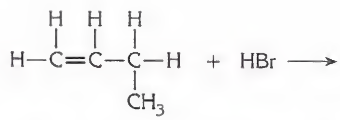
II. It decolorizes brominated water.

III. 1 mole is saturated with 1 gram of H_2.

Which of the above statements is/are correct? (H : 1)

A) I only B) II only C) I and II

D) II and III E) I and III

17. 

What is the compound that is formed in the above reaction?

A) 1-methyl-2-bromopropane
B) 1-bromo-3-methylpropane
C) 2-bromo-3-methylpropane
D) 2-bromobutane
E) 1-bromobutane

18. Which of the following cyclic compounds undergo addition reactions?

A) C_3H_6 B) C_4H_8 C) C_5H_8 D) C_6H_{12} E) C_5H_{10}

19. 30 liters of air is needed to burn 1 liter of an alkene. What is the molecular formula of this alkene?

A) C_2H_4 B) C_3H_6 C) C_4H_8 D) C_5H_{10} E) C_6H_{12}

20. $CH_3-CH=CH-CH_3$

For 1 mol of this compound;

I. It undergoes an addition reaction with 1 mol of H_2.
II. When it is burned, 4 moles of CO_2 is produced.
III. It undergoes an addition reaction with 81 grams of HBr.

Which of the above statements is/are correct?

A) I only B) I and II C) I and III D) II and III E) I, II and III

21. How many liters of oxygen at STP are required to burn the propene gas that is obtained from 1.2 grams of propyl alcohol? (C : 12, H : 1, O : 16)

A) 1.344 B) 1.680 C) 1.792 D) 2.016 E) 2.240

22. 1.4 mol of O_2 is needed to burn 0.2 mole of a cycloalkene completely. What is the number of hydrogen atoms in one molecule of this cycloalkene?

A) 6 B) 8 C) 10 D) 12 E) 14

23. What is the molecular formula of 2, 3, 4 - trimethyl - 1,3 - pentadiene?

A) C_5H_{10} B) C_5H_8 C) C_8H_{16} D) C_8H_{14} E) C_8H_{18}

24. C_3H_6 gas and an excess amount of H_2 are put into a closed container. The gases react with each other until all of the C_3H_6 is consumed. After the reaction and at the initial temperature, the ratio of the initial pressure to the final pressure is found to be 8/7.

According to this data, what is the mass percentage of C_3H_6 in the starting mixture?

A) 12.5 B) 25 C) 40 D) 50 E) 75

25. Which one of the following compounds cannot be obtained from the reaction between 2-chlorobutane and KOH in alcohol solution?

A) Potassium chloride B) 1-butene C) 2-butene D) 1-butyne E) Water

CRISS – CROSS PUZZLE

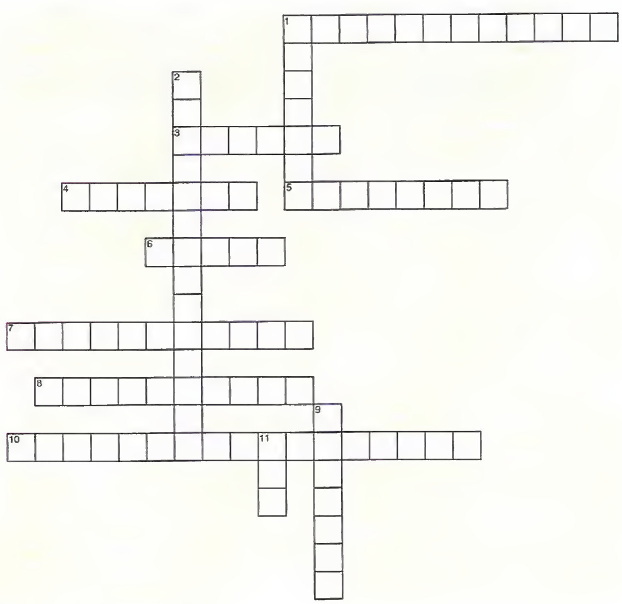
Solve the clues and place your answers in their correct positions in the grid.

CLUES ACROSS

1. This reaction can be used to understand if a compound is an alkene or not.
3. Alkenes which contain 5–17 carbon atoms are in this physical state.
4. Small molecules that react to form polymers.
5. It is the first member of the alkenes.
6. In this isomer substituents are on opposite sides of the double bond.
7. In this process you can produce alkenes by heating alcohols with strong acids.
8. Alkenes which contain 2 double bonds in their structure.
10. It is the long form of PVC.

CLUES DOWN

1. This turns colourless when mixed with alkenes.
2. This is the reaction by which polymers are formed.
9. These are unsaturated hydrocarbons which contain carbon-carbon double bonds.
11. It is an isomer in which the substituents are on the same side of the double bonds.



WORD SEARCH

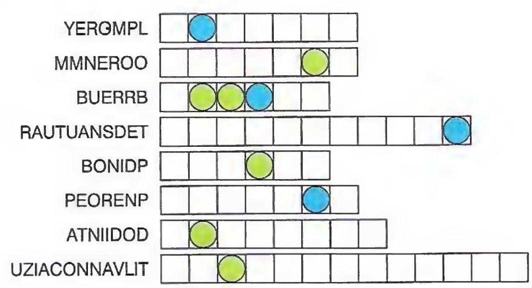
Try to find the hidden words given below.

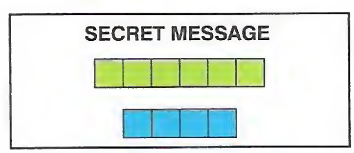
I	O	P	L	N	J	M	E	G	G	M	G	A	D	E	C	H	V
C	S	Y	N	R	N	Z	L	Y	W	E	R	W	M	Y	H	Y	O
M	Z	O	O	F	X	O	E	Q	B	N	N	K	C	G	N	B	K
C	E	T	M	A	T	N	I	Z	H	S	Y	L	R	L	R	R	I
C	M	T	C	E	E	D	T	T	A	I	O	P	H	Y	D	I	N
S	R	X	F	K	R	X	W	A	A	A	Z	O	E	M	P	D	V
O	W	H	L	H	B	I	C	U	L	R	D	T	C	O	Y	I	O
E	R	A	X	M	L	I	S	K	Q	E	D	K	L	S	R	Z	K
T	H	N	H	M	P	P	E	M	T	L	N	Y	P	D	P	A	R
H	E	C	H	C	S	N	N	A	J	G	M	E	H	V	R	T	A
Y	D	O	H	T	E	M	R	E	Y	E	A	B	P	E	C	I	M
L	T	O	F	S	F	U	X	U	R	M	A	L	Y	O	D	O	P
E	V	M	S	Y	T	A	P	C	F	D	I	O	N	S	R	N	N
N	C	T	R	A	N	S	L	Y	N	E	K	L	A	X	T	P	O
E	S	B	S	L	E	A	L	K	A	D	I	E	N	E	S	U	L
O	C	N	C	W	D	P	U	F	V	Q	X	U	Y	J	X	N	F
S	U	D	I	P	P	E	X	X	W	A	Q	V	X	V	V	S	E
F	I	I	S	T	T	A	M	U	N	H	I	J	M	I	K	X	T

ALKADIENES
ALKENE
ALKENYL
BAEYERMETHOD
CIS
CYCLOALKENES
DEHYDRATION
ETHYLENE
HYBRIDIZATION
ISOMERISM
MARKOVNIKOV
POLYMER
PROPENE
PVC
TEFLON
TRANS
UNSATURATED

DOUBLE PUZZLE

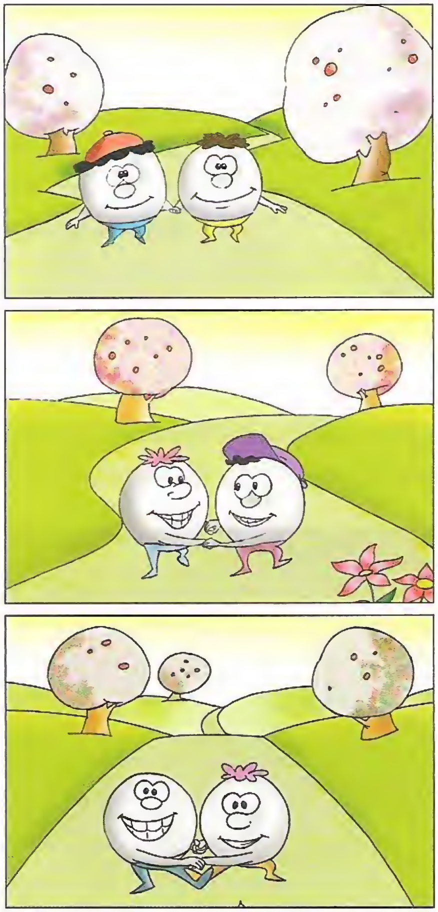
The following words have been jumbled up, you must enter the correct spellings and tranfer the letters in the colored boxes to the secret message.





ALKYNES

HYDROCARBONS



Alkanes, alkenes and alkynes.

INTRODUCTION

Hydrocarbons that contain the carbon-carbon triple bond $-C \equiv C-$ are called alkynes. Each triple bond contains one sigma (σ) and two pi (π) bonds. Because of the π bonds in their structure alkynes are unsaturated hydrocarbons.

The general formula of alkynes is C_nH_{2n-2} where n is an integer starting from 2.

The first member of the alkynes is acetylene (ethyne). The common name for alkynes is the ***acetylenes***.

Alkynes are named by using the *–yne* suffix in place of the *–ane* suffix of alkanes.

Name	Number of Carbon	Molecular Formula	Structural Formula
Ethyne	2	C_2H_2	$CH \equiv CH$
Propyne	3	C_3H_4	$CH \equiv CCH_3$
Butyne	4	C_4H_6	$CH \equiv CCH_2CH_3$
Pentyne	5	C_5H_8	$CH \equiv C(CH_2)_2CH_3$
Hexyne	6	C_6H_{10}	$CH \equiv C(CH_2)_3CH_3$
Heptyne	7	C_7H_{12}	$CH \equiv C(CH_2)_4CH_3$
Octyne	8	C_8H_{14}	$CH \equiv C(CH_2)_5CH_3$
Nonyne	9	C_9H_{16}	$CH \equiv C(CH_2)_6CH_3$
Decyne	10	$C_{10}H_{18}$	$CH \equiv C(CH_2)_7CH_3$

Table 1 : *Some alkynes*

molecular formula	structural formula	alkynyl name
$-C_2H$	$-C \equiv C-H$	Ethynyl
$-C_3H_3$	$-C \equiv C-CH_3$	1–propynyl
$-C_4H_5$	$-C \equiv C-C_2H_5$	3–butynyl

Table 2 : *Some alkynyls*

1. ALKYNYL GROUPS

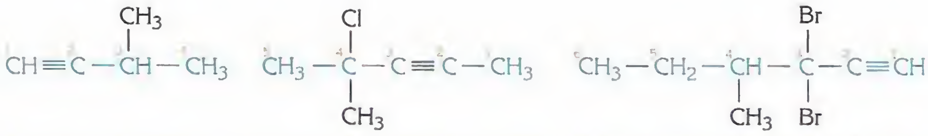
Alkynyl groups are formed from alkynes by removing one H atom. The most common alkynyl groups are ethynyl, 1–propynyl, and 1–butynyl

$$\underset{\text{alkyne}}{C_nH_{2n-2}} \xrightarrow{-H} \underset{\text{alkynyl}}{C_nH_{2n-3}} \qquad \underset{\text{ethyne or acetylene}}{H-C \equiv C-H} \xrightarrow{-H} \underset{\text{ethynyl or acetynyl}}{H-C \equiv C-}$$

The IUPAC name of the simplest alkyne C_2H_2 is ethyne, however it is more often called as acetylene.

2. NOMENCLATURE OF ALKYNES

The naming of alkynes is similar to that of other hydrocarbons. First choose the longest chain containing the triple bond. Then number the carbons in the chain so that the triple bond would be between the carbons with the lowest designated number.



3-methyl-1-butyne 4-chloro-4-methyl-2-pentyne 3,3-dibromo-4-methyl-1-hexyne

Alkynes may contain more than one triple bond. An alkyne with two triple bonds is called an alkadiyne.

$CH\equiv C-C\equiv C-CH_3$

1,3-pentadiyne

$CH\equiv C-C\equiv C-C\equiv C-CH_3$

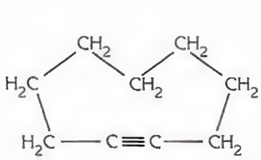
1,3,5-heptatriyne

EXTRA

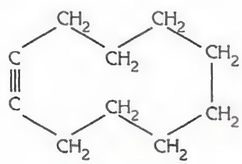
Cycloalkynes

Alkynes may be cyclo compounds the same as alkanes and alkenes. These are known as cycloalkynes.

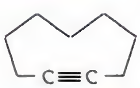
The simplest stable cycloalkyne at room temperature is cyclononyne. Smaller alkynes don't form cyclo compounds, the linear geometry of the ($-C\equiv C-$) structure prevents the formation of small stable cyclo compounds.



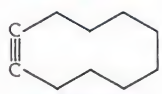
cyclononyne



cyclodecyne



cyclononyne



cyclodecyne

Alkenynes

If a hydrocarbon contains both triple and double bonds, it is named as an alkenyne. The carbon atoms with the double bond bear the smaller number.

$CH_2=CH-C\equiv CH$

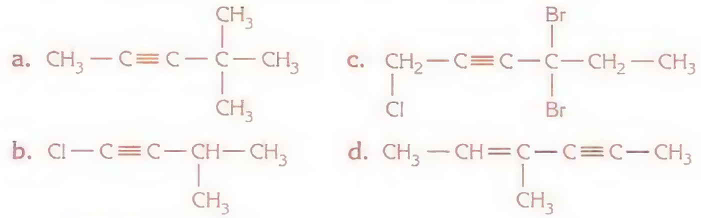
$\underbrace{\text{1 – butene}}_{\text{double bond}}\ -\ \underbrace{\text{3 – yne}}_{\text{triple bond}}$

$CH_3-CH=CH-C\equiv CH_3$

$\underbrace{\text{2 – pentene}}_{\text{double bond}}\ -\ \underbrace{\text{4 – yne}}_{\text{triple bond}}$

Example 1

Name the following alkynes using the IUPAC naming system.



Solution

a. The longest carbon chain has five carbons. The triple bond starts from the second carbon and the fourth carbon has a $-CH_3$ group attached.

4,4-dimethyl-2-pentyne.

b. The longest chain which contains the triple bond has four carbons. The name of the alkyne is 1-butyne. On the first carbon, $-Cl$; on the third carbon, the methyl group is attached. *1-chloro-3- methyl-1-butyne.*

c. The longest carbon chain has six carbons. The triple bond is on the second carbon. On the first carbon there is one $-Cl$, on the fourth carbon two $-Br$ atoms are attached.

1-chloro-4,4-dibromo-2-hexyne.

d. This compound has both double and triple bonds. The double bond is on the second carbon atom. The triple bond is on the fourth carbon. On the third carbon, there is one methyl group.

3-methyl-2-hexene-4-yne.

Example 2

Draw the structural formulae of the given alkynes.

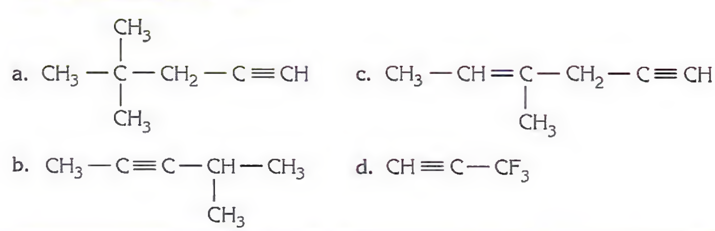
a. 4,4-dimethyl-1-pentyne

b. 4-methyl-2-pentyne

c. 3-methyl-2-hexene-5-yne

d. 3,3,3-trifluoro-1-propyne

Solution



3. ISOMERISM IN ALKYNES

The ($-C\equiv C-$) triple bond may be in different locations in an alkyne, so alkynes can exhibit structural isomerism. For the first two members of alkynes there is only one possible position for ($-C\equiv C-$) bond, so for these cases there is no isomerism.

Structural isomers of alkynes have different physical properties. Alkynes, alkadienes and cycloalkenes containing the same number of carbon atoms are isomers of each other.

However, because of the ($-C\equiv C-$) triple bond, alkynes do not have cis-trans isomers; the carbon – carbon triple bond has a linear geometry.

Some of the possible isomers of C_4H_6 are shown in the Table 3.

Structural formula	Formula	Type of hydrocarbon	Name
H_2C-CH $\vert\quad\ \Vert$ H_2C-CH	C_4H_6	cycloalkene	cyclobutene
$CH_2=C=CH-CH_3$	C_4H_6	alkadiene	1,2-butadiene
$CH_2=CH-CH=CH_2$	C_4H_6	alkadiene	1,3-butadiene
$CH\equiv C-CH_2-CH_3$	C_4H_6	alkyne	1-butyne
$CH_3-C\equiv C-CH_3$	C_4H_6	alkyne	2-butyne

Table 3 : *Some isomers of* C_4H_6.

4. PHYSICAL PROPERTIES OF ALKYNES

The physical properties of alkynes are similar to those of alkanes and alkenes. They are insoluble in water but quite soluble in organic solvents. Densities of liquid alkynes are less than that of water.

At room temperature, the first three members of the series (ethyne, propyne and butyne) are gases, the others are liquids. Branching, as in the other hydrocarbons, decreases the boiling point.

Name	Number of Carbon Atoms	Structural Formula	Melting Point (°C)	Boiling Point (°C)	Density (water = 1)
ethyne (acetylene)	2	$CH\equiv CH$	–80.8	–75.0	
propyne	3	$CH\equiv CCH_3$	–103	–23	
1 – butyne	4	$CH\equiv CCH_2CH_3$	–125.7	8	
2 – butyne	4	$CH_3C\equiv CCH_3$	–32.3	27.0	0.691
1 – pentyne	5	$CH\equiv C(CH_2)_2CH_3$	–106	40	0.69
2 – pentyne	5	$CH_3C\equiv CCH_2CH_3$	–109	56	0.711
1 – hexyne	6	$CH\equiv C(CH_2)_3CH_3$	–132	71	0.716
2 – hexyne	6	$CH_3C\equiv C(CH_2)_2CH_3$	–89	84	0.73
3 – hexyne	6	$CH_3CH_2C\equiv CCH_2CH_3$	–101	81	0.723
1 – heptyne	7	$CH\equiv C(CH_2)_4CH_3$	–81.0	100	0.738
1 – octyne	8	$CH\equiv C(CH_2)_5CH_3$	–79.3	126	0.747
1 – nonyne	9	$CH\equiv C(CH_2)_6CH_3$	–50.0	151	0.758
1 – decyne	10	$CH\equiv C(CH_2)_7CH_3$	–44	174	0.767

Table 4 : *Physical properties of some alkynes.*

Acetylene burns very well

5. CHEMICAL PROPERTIES OF ALKYNES

Alkynes are unsaturated compounds like alkenes and therefore their chemical properties are similar to those of alkenes.

Alkynes undergo combustion reactions and addition reactions, as alkenes do. In addition, alkynes undergo substitution reactions with metals.

5.1. COMBUSTION REACTIONS

Alkynes produce CO_2 and H_2O when they are burnt with a sufficient amount of oxygen. The general combustion reaction is;

$$\boxed{C_nH_{2n-2} + (\frac{3n-1}{2})O_2 \longrightarrow nCO_2 + (n-1)H_2O}$$

$$C_3H_4 + 4\,O_2 \longrightarrow 3\,CO_2 + 2\,H_2O$$

$$2C_4H_6 + 11\,O_2 \longrightarrow 8\,CO_2 + 6\,H_2O$$

Example 3

When 0.1 mole of an alkyne is burnt, 6.72 L of CO_2 gas is produced at STP. What is the molecular formula of this alkyne?

Solution

$$C_nH_{2n-2} + (\frac{3n-1}{2})O_2 \longrightarrow nCO_2 + (n-1)H_2O$$

$$n_{CO_2} = \frac{6.72\text{ L}}{22.4\text{ L/mole}} = 0.3\text{ mole}$$

So according to this;

0.1 mole C_nH_{2n-2}	0.3 mol CO_2
1 mole C_nH_{2n-2}	n mol CO_2

$$n = \frac{1 \cdot 0.3}{0.1} = 3$$

the formula of the alkyne is C_3H_4

Example 4

6.5 mole O_2 gas is required to burn a mixture of butene and pentyne, 4.5 mole of CO_2 is produced after the reaction. How many moles of each compound are in the mixture?

Solution

First, let's write equations for combustion reactions.

$$\underset{x}{C_4H_8} + \underset{6x}{6\,O_2} \rightarrow \underset{4x}{4\,CO_2} + 4\,H_2O$$

$$\underset{y}{C_5H_8} + \underset{7y}{7\,O_2} \rightarrow \underset{5y}{5\,CO_2} + 4\,H_2O$$

The total amount of O_2 is;

$6x + 7y = 6.5$ mol

The total amount of CO_2 that is produced;

$4x + 5y = 4.5$ mol

If we solve these equations;

$5\ /\ 6x + 7y = 6{,}5$ mol

$-7\ /\ 4x + 5y = 4{,}5$ mol

$30x + 35y = 32{,}5$ mol

$-28x - 35y = -31{,}5$ mol

$2x = 1$ mol

$n_{C_4H_8} = x = 0{,}5$ mol C_4H_8

$n_{C_5H_8} = y = 0{,}5$ mol C_5H_8

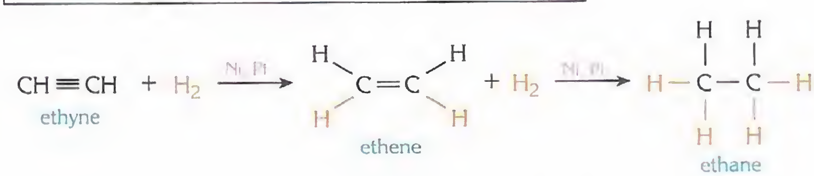
5.2. ADDITION REACTIONS

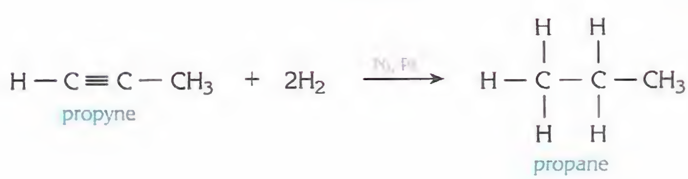
Addition reactions occur by breaking the π bonds of the triple bond. Hydrogen, halogens, hydrogen halides and water may give addition reactions with alkynes.

Addition of Hydrogen

Two hydrogen molecules are added to one triple bond ($-C{\equiv}C-$) using a nickel, platinum or palladium catalyst. Alkenes are the intermediate products.

$$\underset{\text{alkyne}}{C_nH_{2n-2}} \xrightarrow[+H_2]{\text{Ni, Pt}} \underset{\text{alkene}}{C_nH_{2n}} \xrightarrow[+H]{\text{Ni, Pt}} \underset{\text{alkane}}{C_nH_{2n+2}}$$





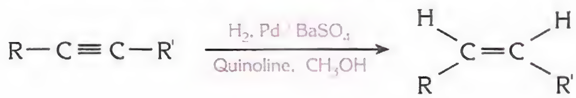
Alkanes don't undergo hydrogenation reactions

EXTRA

Cis or Trans

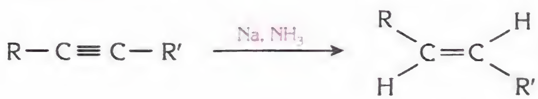
When alkanes undergo addition reactions, the first step product of the reaction is an alkene. This product, the alkene, may be a cis or a trans compound depending upon the reaction conditions.

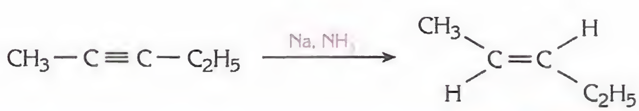
If Lindlar's catalyst is used in the reaction, the product is a cis compound. Lindlar's catalyst is a partially deactivated catalyst consisting of barium sulfate, palladium and quinoline.



cis – 2 – heptene

However, trans alkenes are produced by the action of sodium metal in liquid ammonia.

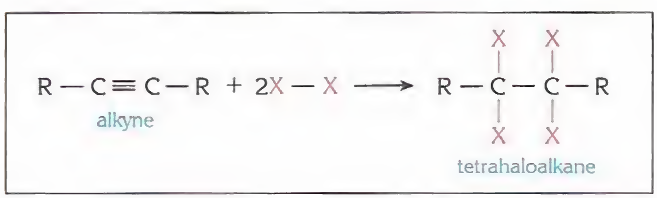


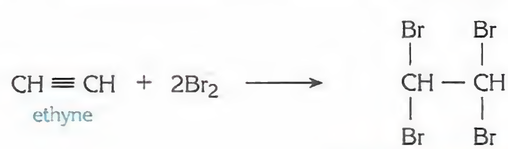


trans – 2 – pentene

Addition of Halogens

Alkynes undergo addition reactions with halogens (Cl_2, Br_2) to produce tetrahalo alkanes. To saturate each alkyne molecule, two halogen molecules are needed. Alkynes decolorize aqueous Br_2 solution, as alkenes do.





1,1,2,2-tetrabromoethane

Example 5

A 10 mole mixture of propyne and methane undergoes an addition reaction with 4 moles of H_2. After the reaction has finished, there are only propane and methane gases left in the container. What is the number of moles of CH_4 in the initial mixture?

Solution

In the mixture of C_3H_4 and CH_4, only C_3H_4 undergoes an addition reaction with H_2. Since CH_4 is a saturated hydrocarbon, it doesn't react with H_2.

The addition reaction of C_3H_4 with H_2 ;

$$C_3H_4 + 2\,H_2 \longrightarrow C_3\,H_8$$

According to the equation;

1 mol of C_3H_4	reacts with	2 mol of H_2
x mol of C_3H_4	reacts with	4 mol of H_2

$n_{C_3H_4} = 2$ mol

The initial mixture is 10 moles. So;

$n_{mix} = n_{CH_4} + n_{C_3H_4} \qquad n_{CH_4} = n_{mix} - n_{C_3H_4}$

$n_{CH_4} = 10$ mol – 2 mol = 8 mol

Example 6

0.3 mole of a mixture of propyne and propene can be saturated with 0.4 mole of Cl_2. What are the number of moles of propyne and propene in the mixture?

Solution

$$\underset{x\ mol}{C_3H_4} + \underset{2x\ mol}{2\,Cl_2} \longrightarrow C_3H_4Cl_4$$

$$\underset{y\ mol}{C_3H_6} + \underset{y\ mol}{Cl_2} \longrightarrow C_3H_6Cl_2$$

According to the equations, x mole C_3H_4 is saturated with 2 x moles of Cl_2 and y mole C_3H_6 is saturated with y mole of Cl_2 gas.

Gas mixture is $\quad x + y = 0.3$ mol

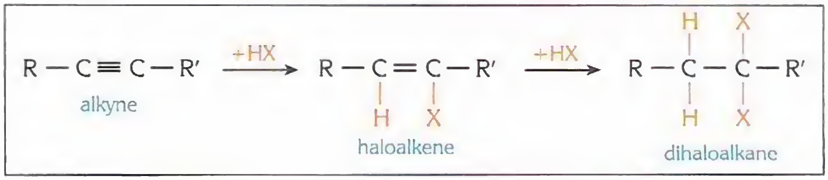
Chlorine $\quad 2x + y = 0.4$ mol

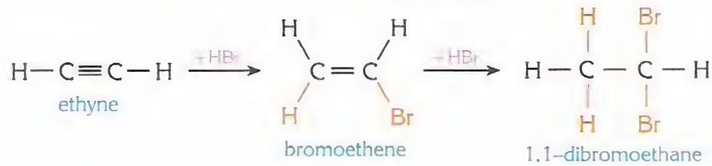
$n_{C_3H_4} = x = 0.1$ mol propyne

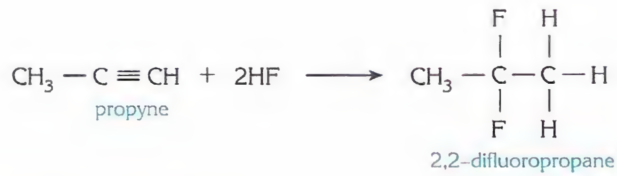
$n_{C_3H_6} = y = 0.2$ mol propene

Addition of Hydrogen Halides

Hydrogen halides, HX, are added to alkynes according to Markovnikov's rule.



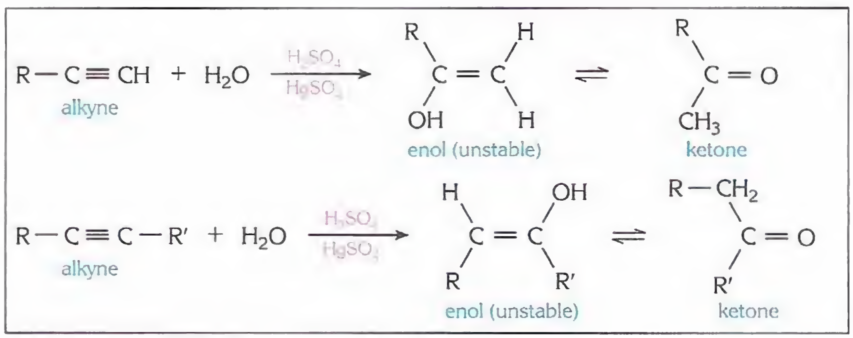




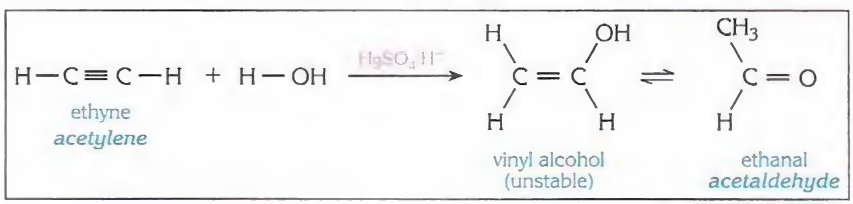
Addition of Water

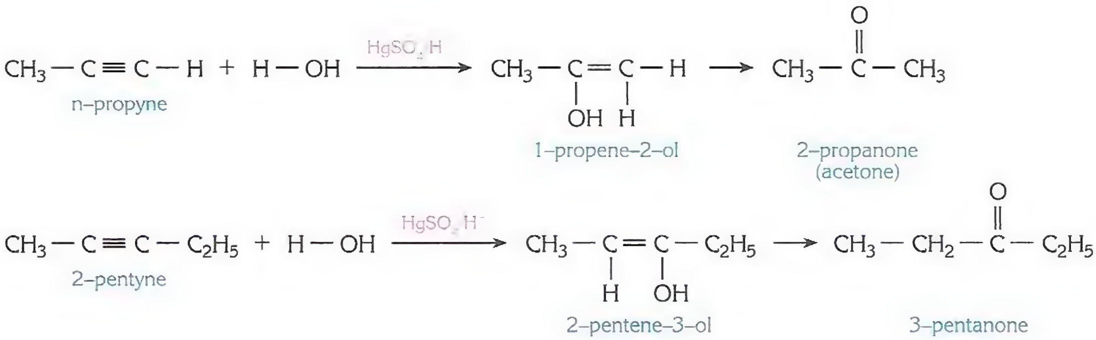
A mixture of mercury (II) sulfate, $HgSO_4$, and sulfuric acid enables water to add to alkynes.

In this reaction, $HgSO_4$ weakens the triple bond. When water is added to an alkyne, the first product is an enol. However enols are unstable and they readily rearrange to form a ketone or an aldehyde. If the alkyne has a RC≡CH or RC≡CR structures, a ketone forms.



When water is added to acetylene (HC≡CH) acetaldehyde forms.



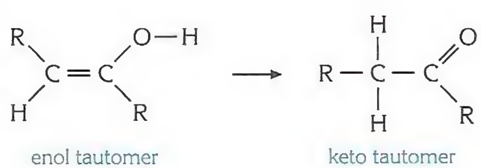


There is an equilibrium between the keto group (aldehyde or ketone) and the enol group that is known as keto-enol tautomerization.

EXTRA

Enol – Ketone Tautomerism

Enols are organic compounds that have a hydroxyl group bonded to a carbon atom that is attached to another carbon atom by a double bond. Change in bond energies shows that the event is exothermic so potential energy of keto tautomer is lower than that of enol tautomer. It means that keto tautomer is more stable.



Broken bonds		Formed bonds	Change In Bond Energy
C=C 146	→	C–C 83	+63
C–O 85,5	→	C=O 178	–92.5
C–H 111	→	C–H 99	+12
			–17.5 kcal/mol

5.3. SUBSTITUTION REACTIONS WITH METALS

The –C≡C– carbon atoms in alkynes are very close to each other and this in turn weakens the C–H bond. This enables the H atom to leave easily from the R–C≡C–H molecule. As a result, alkynes with the R–C≡C–H formula show weak acidic properties. Because of this acidity, alkynes can react with some metal salts to form alkyl metal acetylene salts. If an alkyne has the structure R–C≡C–R, however, there is no reaction.

When silver nitrate ($AgNO_3$) or copper (I) chloride (Cu_2Cl_2) in NH_3 solution is added to R–C≡C–H, copper acetylide or silver acetylide salts are formed. These are insoluble in water, and when dried and heated, explode. This reaction is useful to differentiate terminal alkynes from non–terminal ones. Terminal alkynes are the ones with the triple bond at the end of the chain.

$$R-C\equiv CH + AgNO_3 \xrightarrow{+NH_3} R-C\equiv C-Ag\downarrow + NH_4NO_3$$

alkyne — alkyl silver acetylide, white precipitation

$$2R-C\equiv CH + Cu_2Cl_2 \xrightarrow{+2NH_3} 2R-C\equiv C-Cu\downarrow + 2NH_4Cl$$

alkyne — alkyl copper – I – acetylide, red precipitation

$$R-C\equiv C-R' + AgNO_3 \text{ (or } Cu_2Cl_2) \longrightarrow \text{No reaction}$$

$$CH_3-C\equiv CH + AgNO_3 \xrightarrow{+NH_3} CH_3-C\equiv C-Ag + NH_4NO_3$$

propyne — methyl silver acetylide

$$2CH_3-C\equiv CH + Cu_2Cl_2 \xrightarrow{+2NH_3} 2CH_3-C\equiv C-Cu + 2NH_4Cl$$

propyne — methyl copper acetylide

EXTRA

Acidity of Hydrocarbons

C–H bonds in hydrocarbons have a very weak tendency to be ionized. Thus, alkanes, alkenes and alkynes show weak acid properties. Conjugate bases of hydrocarbons are called carbanions.

$$CH_4 \rightleftharpoons H^+ + H-\overset{H}{\underset{H}{\overset{|}{\underset{|}{C}}}}^{\ominus}- \quad : sp^3$$

methane — proton — methyl ion

$$C_2H_4 \rightleftharpoons H^+ + H_2C=\overset{\ominus}{C}-H \quad : sp^2$$

ethene — proton — vinyl ion

$$C_2H_2 \rightleftharpoons H^+ + H-C\equiv \overset{\ominus}{C}- \quad : sp$$

ethyne — proton — acetyl ion

the sp^3 orbital in an alkane has 25 % s character,

the sp^2 orbital in an alkene has 33,3 % s character,

the sp orbital in an alkyne has 50 % s character,

Reasons for alkyne acidity.

Consider what happens when an alkyne loses a hydrogen ion. The bond is broken. The electron pair of the bond is now an unshared pair in an sp hybridized orbital. The sp orbital has considerable s character, the s orbitals are close to the nucleus so the nuclear attraction to these electrons is greater in an sp orbital than in an sp^2 or sp^3 orbital. This stabilizes the negative charge, making it easier to remove the hydrogen ion, hence, the alkyne is more acidic. The lengths of the C—C bonds are as follows.

$C\equiv C$	$C=C$	$C-C$
121 pm	134 pm	154 pm
sp	sp^2	sp^3

Acidity

$$CH\equiv CH \;>\; CH_2=CH_2 \;>\; CH_3-CH_3$$

$$Ka = 10^{-26} \qquad Ka = 10^{-45} \qquad Ka = 10^{-62}$$

Example 7

$HC\equiv CR + AgNO_3 \longrightarrow AgC\equiv CR(s) + NH_4NO_3$

According to this reaction, 0.1 mole of alkyne reacts with $AgNO_3$ to produce 16.1 grams of white precipitate. What is R in the alkyne? (Ag: 108, C:12, H:1)

Solution

According to equation, from 1 mol alkyne, 1 mol precipitate (alkyl silver acetylide) is produced. The amount of the alkyne in the question is 0,1 mol. Thus the white precipitate should be 0.1 mol too.

0.1 mol alkyl silver acetylide	16.1 g
1 mol alkyl silver acetylide	x

$M_{AgC_2R} = x = 161$ g/mol

$108 + 12 + 12 + M_R = 161$

$M_R = 29$ g/mol. The general formula of R is C_nH_{2n+1}

$12 \cdot n + (2n+1) = 29 \qquad n = 2 \qquad R = C_2H_5$

Example 8

Complete the following reactions and write the names of the products.

a. 2–hexyne + Br_2 (excess) $\longrightarrow$

b. 1–butyne + $H_2O \xrightarrow{HgSO_4\,/\,H^+}$

c. dimethyl acetylene + $AgNO_3 + NH_3 \longrightarrow$

Solution

a. $\underset{\text{2–hexyne}}{CH_3-C\equiv C-C_3H_7} + 2Br_2 \longrightarrow \underset{\text{2,2,3,3–tetrabromohexane}}{CH_3-\overset{\overset{Br}{|}}{\underset{\underset{Br}{|}}{C}}-\overset{\overset{Br}{|}}{\underset{\underset{Br}{|}}{C}}-C_3H_7}$

b. $\underset{\text{1–butyne}}{C_2H_5-C\equiv CH} + H_2O \xrightarrow{HgSO_4/H^+} \underset{\text{1–butene–1–ol}}{C_2H_5-\underset{\underset{H}{|}}{C}=\underset{\underset{OH}{|}}{CH}} \rightleftharpoons \underset{\text{butanal}}{C_2H_5-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-\underset{\underset{H}{|}}{C}=O}$

c. $CH_3-C\equiv C-CH_3 + AgNO_3 + NH_3 \longrightarrow$ no reaction.
2–butyne (dimethyl acetylene)

There is no hydrogen atom next to the triple bond $-C\equiv C-$ in 2-butyne. So no reaction takes place.

6. PREPARATION OF ALKYNES

6.1. BY THE REACTION OF METAL ACETYLIDES AND ALKYL HALIDES

Alkynes can be synthesized from metallic acetlylides and alkyl halides.

$$\underset{\text{sodium acetylide}}{CH\equiv C-Na} + \underset{\text{alkyl halide}}{RX} \longrightarrow \underset{\text{alkyne}}{CH\equiv C-R} + \underset{\text{sodium halide}}{NaX}$$

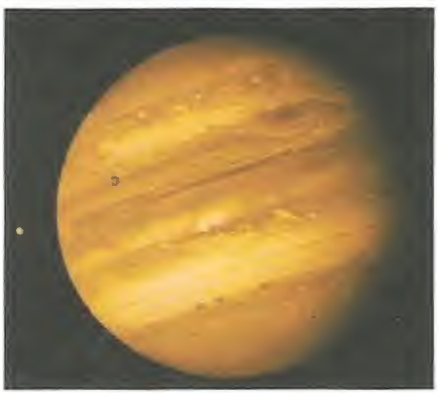
$$\underset{\text{sodium acetylide}}{CH\equiv C-Na} + \underset{\text{1-bromobutane}}{CH_3CH_2CH_2CH_2Br} \longrightarrow \underset{\text{1-hexyne}}{CH_3CH_2CH_2CH_2C\equiv CH} + NaBr$$

6.2. DEHALOGENATION OF DIHALOALKANES

If a dihaloalkane is heated in alcoholic KOH solution, the two halogen atoms, bonded to the neighbour carbons, are eliminated and the alkane forms a triple bond and becomes an alkyne. This reaction is called an ***elimination reaction***.

$$\underset{\text{1,2-dihaloalkane}}{R-\begin{array}{c}H\\|\\C\\|\\X\end{array}-\begin{array}{c}H\\|\\CH\\|\\X\end{array}} + 2KOH \xrightarrow[\text{heat}]{\text{alcohol}} \underset{\text{alkyne}}{R-C\equiv CH} + 2HOH + 2KX$$

$$\underset{\text{1,2-dibromopropane}}{CH_3-\begin{array}{c}H\\|\\C\\|\\Br\end{array}-\begin{array}{c}H\\|\\C\\|\\Br\end{array}-H} + 2KOH \xrightarrow[\text{heat}]{\text{alcohol}} \underset{\text{propyne}}{CH_3-C\equiv CH} + 2H_2O + 2KBr$$



In the atmosphere of Jupiter, acetylene molecules have been detected.

7. ACETYLENE

Acetylene, the first member of the alkyne series, is one of the major chemicals used in industry.

7.1. PHYSICAL PROPERTIES

Pure acetylene has a very light odor and is a colorless gas. It is soluble in water and highly soluble in acetone. In industry, it is mixed with PH_3 and H_2S which cause it to smell very bad.

It boils at $-83°C$ and can be liquified at 1°C. When it is liquified, it becomes extremely explosive, so it is dissolved in acetone.

7.2. CHEMICAL PROPERTIES

Acetylene undergoes all the reactions of alkynes.

1. It burns with a bright flame.

$$2C_2H_2 + 5O_2 \longrightarrow 4CO_2 + 2H_2O$$

Acetylene gas explodes at about 15 atm pressure. Because of this it is stored under low pressure (less than 10 atm.)

2. It undergoes addition reactions with hydrogen, halogens, hydrogen halides and water.

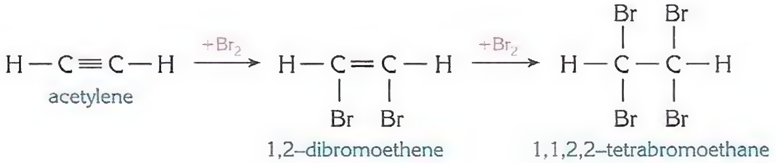
a. Addition of Hydrogen

If hydrogen is added to acetylene, ethylene is formed as an intermediate product and after that ethane is produced.

$$\underset{\text{acetylene}}{H-C\equiv C-H} \xrightarrow{+H_2} \underset{\substack{\text{ethene}\\\text{(intermediate)}}}{H_2C=CH_2} \xrightarrow{+H_2} \underset{\text{ethane}}{H_3C-CH_3}$$

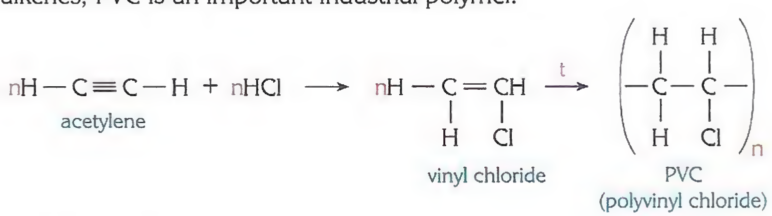
b. Addition of Halogens

If a halogen is added to acetylene, first the dihaloethene is produced as an intermediate product. Then, the tetrahaloethane is produced.



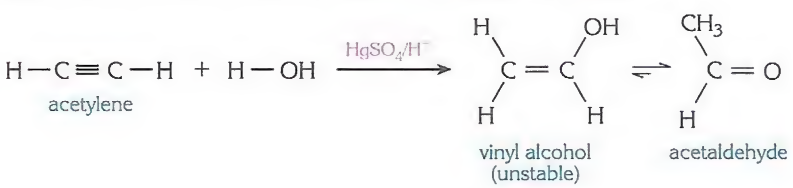
c. Addition of Hydrogen Halides

Acetylene reacts with HCl to produce vinyl chloride which polymerizes to produce polyvinyl chloride, PVC. As we have seen in the polymerization of alkenes, PVC is an important industrial polymer.



d. Addition of Water

When water is added to acetylene in the presence of the catalysts mercury (II) sulfate and dilute sulfuric acid, acetaldehyde is formed.



Acetylene is used for welding with O_2. At 3300°C two metals can be welded to each other.

Acetylene gas is used in welding.

Since the brightness of the flame of acetylene, it was often used as a light source before the discovery of electricity.

In addition to these reactions, acetylene reacts with hydrogen cyanide, HCN. In this reaction, acrylonitrile is formed.

$$H-C\equiv C-H \;+\; H-C\equiv N \xrightarrow[80^{\circ}C]{Cu_2Cl_2} \underset{\substack{\text{acrylonitrile} \\ \textit{vinyl cyanide}}}{CH_2=\overset{\overset{\displaystyle H}{|}}{C}-C\equiv N}$$

3. When acetylene is treated with ammoniacal solutions of Cu_2Cl_2 or $AgNO_3$, both hydrogen atoms are displaced by the metals.

$$H-C\equiv C-H \;+\; Cu_2Cl_2 \xrightarrow{+2NH_3} \underset{\substack{\text{copper acetylide} \\ \text{(red-brown)}}}{Cu-C\equiv C-Cu\downarrow} + 2NH_4Cl$$

$$H-C\equiv C-H \;+\; 2AgNO_3 \xrightarrow{+2NH_3} \underset{\substack{\text{silver acetylide} \\ \text{(white)}}}{Ag-C\equiv C-Ag\downarrow} + 2NH_4NO_3$$

Example 9

When a 0.20 mol mixture of ethane, ethylene and acetylene is passed through ammoniacal Cu_2Cl_2 solution, 7.6 grams of precipitate is formed. The remaining mixture is passed through bromine solution and 8 grams of bromine is used up. How many moles of ethane were there in the original mixture?

(Cu : 64, C : 12, Br : 80, H : 1)

Solution

When the mixture is passed through ammoniacal Cu_2Cl_2 solution; the only reaction is with acetylene (C_2H_2). This is;

$$C_2H_2 + Cu_2Cl_2 \longrightarrow Cu-C\equiv C-Cu + 2NH_4Cl$$

$$n_{Cu_2C_2} = \frac{7.6\text{ g}}{152\text{ g/mol}} = 0.05\text{ mol}$$

Thus;

$$\begin{array}{ll} 1\text{ mol } C_2H_2 & 1\text{ mol } Cu_2Cl_2 \\ x\text{ mol } C_2H_2 & 0.05\text{ mol } Cu_2Cl_2 \\ \hline \end{array}$$

$$n_{C_2H_2} = x = 0.05\text{ mol}$$

So the amount of C_2H_2 in the mixture is 0.05 mole.

When the remaining mixture (ethane + ethylene) is passed through bromine solution the only reaction is with ethylene.

The equation for this reaction is;

$$C_2H_4 + Br_2 \longrightarrow C_2H_4Br_2$$

$$n_{Br_2} = \frac{8\ g}{160\ g/mol} = 0.05\ mol$$

$$\begin{array}{ll} 1\ mol\ \ C_2H_4 \text{ reacts with} & 1\ mol\ Br_2 \\ x\ mol\ \ C_2H_4 \text{ reacts with} & 0.05\ mol\ Br_2 \\ \hline n_{C_2H_4} = x = 0.05\ mol & \end{array}$$

Initially, the mixture was 0.20 mol

$$n_{C_2H_2} + n_{C_2H_4} + n_{C_2H_6} = 0.20\ mol$$

$$0.05\ mol + 0.05\ mol + n_{C_2H_6} = 0.20\ mol$$

$$n_{C_2H_6} = 0.10\ mol$$

Example 10

When 0.10 mole of a mixture of acetylene and ethane is passed through ammoniacal silver nitrate solution, 9.60 grams of a white precipitate is formed. What is the mole percentage of acetylene in the mixture?

(Ag : 108, C : 12)

Solution

When the gas mixture is passed through ammonical silver nitrate solution, acetylene reacts but ethane doesn't.

$$\underset{\text{acetylene}}{C_2H_2} + 2AgNO_3 \xrightarrow{NH_3} \underset{\text{silver acetylide}}{Ag-C\equiv C-Ag\downarrow} + 2NH_4NO_3$$

The molecular weight of silver acetylide is;

$$M_{Ag_2C_2} = 2 \cdot 108 + 2 \cdot 12 = 240\ g/mol$$

Mole number;

$$n_{Ag_2C_2} = \frac{m}{M} = \frac{9.6\ g}{240\ g/mol} = 0.04\ mol$$

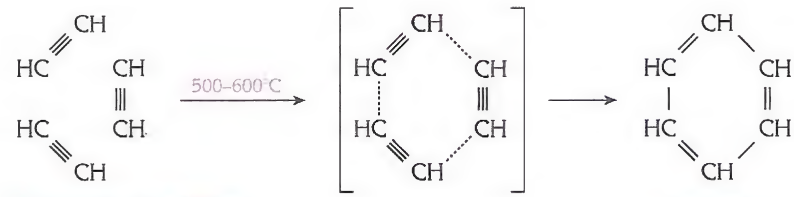
Thus; the amount of acetylene is 0.04 mole as well.

$$C_2H_2\% = \frac{0.04}{0.10\ mol} \cdot 100 = 40$$

4. Acetylene undergoes dimerization and trimerization reactions. When acetylene is passed into a solution of Cu_2Cl_2 and ammonium chloride, it forms vinyl acetylene which is used in the preparation of synthetic rubber, an important material in the plastics industry.

$$CH \equiv CH + CH \equiv CH \xrightarrow[NH_4Cl]{Cu_2Cl_2} \underset{\substack{\text{1-butene-3-yne} \\ \textit{vinyl acetylene}}}{CH_2 = CH - C \equiv CH}$$

When acetylene is passed through a red hot copper tube, benzene is formed (trimerization).



3 molecules of acetylene

benzene

7.3. PREPARATION OF ACETYLENE

Preparation of acetylene from CaC_2

a. The preparation of acetylene from calcium carbide is the most important preparation method. When quicklime and coke react with each other at high temperature, calcium carbide is formed. The reaction of calcium carbide with water produces acetylene.

$$\underset{\text{quicklime}}{CaO} + \underset{\text{coke}}{3C} \xrightarrow{2000\,^{\circ}C} \underset{\text{calcium carbide}}{CaC_2} + CO$$

$$CaC_2 + 2H_2O \longrightarrow \underset{\text{acetylene}}{CH \equiv CH} + Ca(OH)_2$$

b. Acetylene can be produced by any of the general methods by which other alkynes are prepared. For example, when 1,2 – dibromoethane reacts with KOH solution dissolved in alcohol, acetylene is produced.

$$\underset{\text{1,2-dibromoethane}}{H-\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}-H} + 2KOH \xrightarrow[\text{heat}]{\text{alcohol}} \underset{\text{acetylene}}{CH \equiv CH} + 2KBr + 2H_2O$$

c. The elements carbon and hydrogen can be reacted together in an electric arc to produce acetylene.

$$2C + H_2 \xrightarrow{\text{electric arc}} \underset{\text{acetylene}}{CH \equiv CH}$$

Example 11

When 5 grams of impure CaC_2 is added to water, 1.12 L of acetylene is produced at STP. What is the percentage purity of the CaC_2 sample?

(CaC_2 : 64)

Solution

First, let us write the reaction of CaC_2 with water.

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

at STP

$$n_{C_2H_2} = \frac{1.12\ L}{22.4\ L/mol} = 0.05\ mol$$

According to the equation;

The ratio calcium to acetylene is one to one so their mole numbers are equal.

$$n_{CaC_2} = n_{C_2H_2} = 0.05\ mol$$

$$m_{CaC_2} = n \cdot M \quad \Rightarrow \quad 0.05\ mol \cdot 64\ g/mol = 3.2\ g$$

Then, $\quad CaC_2\% = \dfrac{3.2\ g}{5\ g} \cdot 100 = 64$

Example 12

Starting from $CaCO_3$, obtain

a. acetylene **b.** ethylene **c.** ethane

Solution

$$CaCO_3(s) \xrightarrow{heat} CaO(s) + CO_2(g)$$

From the CaO product:

a. $CaO(s) + 3C \longrightarrow CaC_2 + CO$

$CaC_2 + 2H_2O \longrightarrow HC \equiv CH + Ca(OH)_2$

b. $CH \equiv CH + H_2 \xrightarrow{\text{Lindlar's Catalyst}} \underset{\text{ethene (ethylene)}}{CH_2 = CH_2}$

c. $\underset{\text{ethylene}}{CH_2 = CH_2} + H_2 \xrightarrow{Pt} \underset{\text{ethane}}{CH_3 - CH_3}$

SUPPLEMENTARY QUESTIONS

1. 1 mole of a hydrocarbon contains 3 moles of sigma and 2 moles of pi bonds.

   Write down the formula of this compound.

2. What is the molecular formula of an alkyne of which 0.63 grams contains 0.07 grams of H?

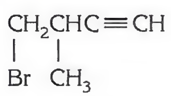
3. $CH_3-C\equiv C-CH=CH_2$

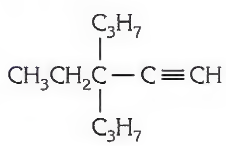
   What are the types of hybridizations undergone by the carbon atoms in this compound?

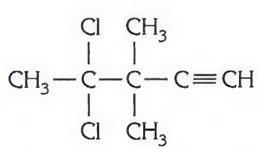
4. Name the following compounds using the IUPAC system.

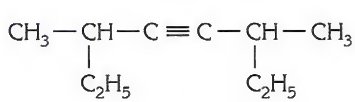
   a. $CH\equiv CH$

   b. $CH_3CH_2C\equiv CH$

   c. 

   d. 

   e. 

   f. 

5. Write the structural formulae of the compounds given below.

   a. 2 - pentyne

   b. 4 - methyl - 2 - pentyne

   c. 3 - chloro - 1 - butyne

   d. 3 - chloro - 2 - ethyl - 1 - pentyne

   e. dicyclohexyl acetylene

   f. 8–bromo–2, 7, 8–trimethyl–4–nonyne

6. Write two possible

   a. alkyne

   b. alkadiene

   c. cycloalkene

   structures which have the C_5H_8 formula and name these compounds.

7. Draw the structural formulae and name six isomers of C_4H_6.

8. What can be said about the product that is formed by the addition reaction of equal moles of H_2 and acetylene? Write the reaction equation.

9. 2.24 L H_2 at STP is needed to saturate 2 grams of an alkyne? What is the molecular formula of this alkyne?

10. 0.7 mole of a mixture of butyne and butene is completely saturated by 22.4 L of H_2 at STP. At the end of the reaction, there is only butane (C_4H_{10}) gas left in the container. What was the mass of the initial mixture?

11. 0.3 mole of Br_2 is used to saturate a mixture containing equal moles of ethylene and acetylene. What is the mass of acetylene in this mixture?

12. There are propane, ethylene and acetylene in separate containers. How can we identify the gases?

13. Propose a method to differentiate the compounds 1 - butyne, 1,3 - butadiene and butane gas which are stored in three different containers.

14. 28 liters of CO_2 at STP is released by burning 0.25 mole of an alkyne. According to this information;
    a. What is the molecular formula of the alkyne?
    b. What volume of air at STP is used in the combustion reaction? (21% of air is oxygen by volume)
    c. How many grams of H_2O are produced?

15. In a combustion reaction the mass of produced water is equal to the mass of the combusted alkyne.
    a. What is the molecular formula of the alkyne?
    b. What is the volume ratio of CO_2 produced to O_2 consumed (assuming the same conditions)?

16. What is the molecular formula of an alkyne if 13.44 liters of CO_2 at STP and 5.4 grams of H_2O is produced after it is burned?

17. When 20 cm^3 of a hydrocarbon and 100 cm^3 of oxygen is burned, 20 cm^3 of oxygen gas remains in excess and 60 cm^3 of CO_2 is produced. What is the molecular formula of the hydrocarbon?

18. When a mixture containing equal moles of ethylene and acetylene, is passed through ammoniacal silver nitrate solution, 36 grams of a white precipitate is formed in the container. What is the volume of the initial gas mixture at STP? (H : 1, C : 12, Ag : 108)

19. What is the name and mass of the alkyne that is produced by the reaction of 14.4 grams of sodium acetylide with an excess of ethyl bromide?

20. 0.2 mole of KOH and an excess amount of 1.2 – dichloro ethane are reacted together in the presence of alcohol. How many liters of air is needed to burn the product of this reaction at STP?

21. How would you carry out the following transformations.
    $C \rightarrow CaC_2 \rightarrow C_2H_2 \rightarrow C_2H_4 \rightarrow CO_2$

22. Write the equations of the reactions that take place between the following pairs:
    a. Acetylene and oxygen
    b. 2–butyne and hydrogen (with Lindlar's catalyst)
    c. Propyne and silver nitrate (in NH_3)
    d. 1–pentyne and water.

MULTIPLE CHOICE QUESTIONS

1. I. Acetylene

   II. Cyclopropane

   III. Cis-2-butene

   In which of the compounds given above do the carbon atoms undergo only sp hybridization?

   A) I only B) II only C) III only D) I and II E) I, II and III

2. Which of the given acyclic compounds can decolorize bromine water?

   I. C_6H_{10}

   II. C_4H_{10}

   III. C_5H_{10}

   A) I only B) II only C) I and II D) I and III E) I, II and III

3. The names of three compounds are given below.

   I. $CH_3-C\equiv C-CH_3$ 2 – butyne

   II. $CH_3-C\equiv CH$ 2 – propyne

   III. $CH\equiv C-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3$ 2 – methyl – 3 – butyne

   Which of them is/are named correctly?

   A) I only B) II only C) I and II D) I and III E) II and III

4. I. Acetylene

   II. 1,3 - pentadiene

   III. 2 - butene

   If we have 1 mole of each of the compounds above, to which one(s) can 2 moles of H_2 be added?

   A) I only B) II only C) I and II D) II and III E) I, II and III

5. A 30 L of mixture of C_2H_2 and C_2H_4 is saturated with 50 L of H_2. What is the mole percentage of acetylene in the mixture?

   A) 25% B) 50% C) 75% D) 33% E) 67%

6. Which one of the given compounds below will not change the color of bromine water?

   A) C_2H_2 B) C_2H_4 C) C_3H_4 D) CH_4 E) C_3H_6

7. $CH_3-C\equiv C-CH_3$

   $CH_2=CH-CH=CH_2$

   2 moles of Br_2 is added to one mole of each of above compounds. Which property is/are the same for the reaction products?

   I. Molecular formula

   II. Molecular weight

   III. Structural formula

   A) I only B) II and III C) I and III D) I and II E) I, II and III

8. Propyne is saturated with an excess of HBr. What is the name of the product?

A) 2,2-dibromopropane

B) 2-bromopropane

C) 2,2-dibromopropene

D) 2-bromopropene

E) propane

9. I. If water is added to ethylene, ethyl alcohol is produced.

II. If water is added to acetylene, acetaldehyde (ethanal) is produced.

III. If water is added to propyne, dimethyl ketone (2–propanone) is produced.

Which of the above statements is/are correct?

A) I only B) I and II C) II and III

D) I and III E) I, II and III

10. $CH_3-C\equiv C-Na + CH_3-Cl \rightarrow$

Which one of the names below is the correct hydrocarbon produced in this reaction?

A) 2-butyne B) 1-butyne C) 2-butene

D) Butane E) Propyne

11. With ammoniacal $AgNO_3$ solution;

I. $H-C\equiv C-H$

II. $CH_3-C\equiv C-H$

III. $CH_3-C\equiv C-CH_3$

which of the above undergoes a reaction?

A) I only B) I and II C) II and III

D) III only E) I, II and III

12. When 11 grams of a mixture of C_2H_6, C_2H_4 and C_2H_2 gases is passed through ammoniacal $AgNO_3$ solution, 12 grams of silver acetylide precipitates. The remaining mixture is passed through brominated water and 24 grams of Br_2 is used up.

What is the mass percentage of C_2H_6 in the mixture?

(H : 1, C : 12, Br : 80, Ag : 108)

A) 25 B) 35 C) 50 D) 60 E) 75

13. For the compound $CH_3-CH_2-C\equiv CH$

I. It undergoes a reaction with ammoniacal $AgNO_3$ solution.

II. It decolorizes bromine water.

III. It undergoes an addition reaction with hydrogen.

Which of the above statements is/are correct?

A) I only B) II only C) III only

D) I and II E) I, II and III

PUZZLE

WORD SEARCH

CLUES

The replacement of a hydrogen atom of a hydrocarbon by another atom or group of atoms is called a ____________ reaction.

The individual, small units that make up a polymer. ____________

A compound with a different structure from another compound with the same formula. ____________

An unsaturated hydrocarbon that contains a triple bond between two carbon atoms. ____________

A large molecule that is made up of many small repeating units. ____________

A hydrocarbon that has one or more double or triple bonds between the carbon atoms. ____________

____________ reactions occur by breaking the pi bonds in the triple bond. Hydrogen, halogens, hydrogen halides and water may all undergo ____________ reactions with alkynes.

It is the first member of the alkyne series which is one of the major chemicals used in industry. ____________

The alkyne containing five carbon atoms. ____________

E	M	E	W	C	X	A	E	S	T	T	P	N	Y	S
U	T	N	T	R	X	N	H	U	A	E	Q	O	C	E
O	A	Y	Q	T	T	Y	M	R	Z	D	R	I	I	E
N	C	K	D	S	E	R	Z	U	E	R	X	T	N	B
V	Y	L	A	P	Y	P	K	T	P	L	Z	U	V	R
I	K	A	R	J	O	U	A	L	M	J	B	T	M	F
R	N	N	K	L	Q	R	E	E	U	S	N	I	O	O
A	O	V	Y	F	U	U	F	A	W	N	E	T	N	I
V	D	M	F	T	E	N	Y	T	N	E	P	S	O	K
R	E	D	A	C	E	T	Y	L	E	N	E	B	M	Y
R	E	S	I	K	G	W	Y	O	T	Y	G	U	E	G
D	N	M	P	T	B	Q	O	S	T	N	H	S	R	V
U	X	A	O	K	I	X	O	R	V	O	X	T	L	M
C	Q	P	Y	S	H	O	R	U	T	Z	F	O	O	P
U	V	X	H	S	I	G	N	E	B	V	Y	J	B	L

CRYPTOGRAM

Below is a phrase about bonding. Try to find out the whole phrase with the given clues.

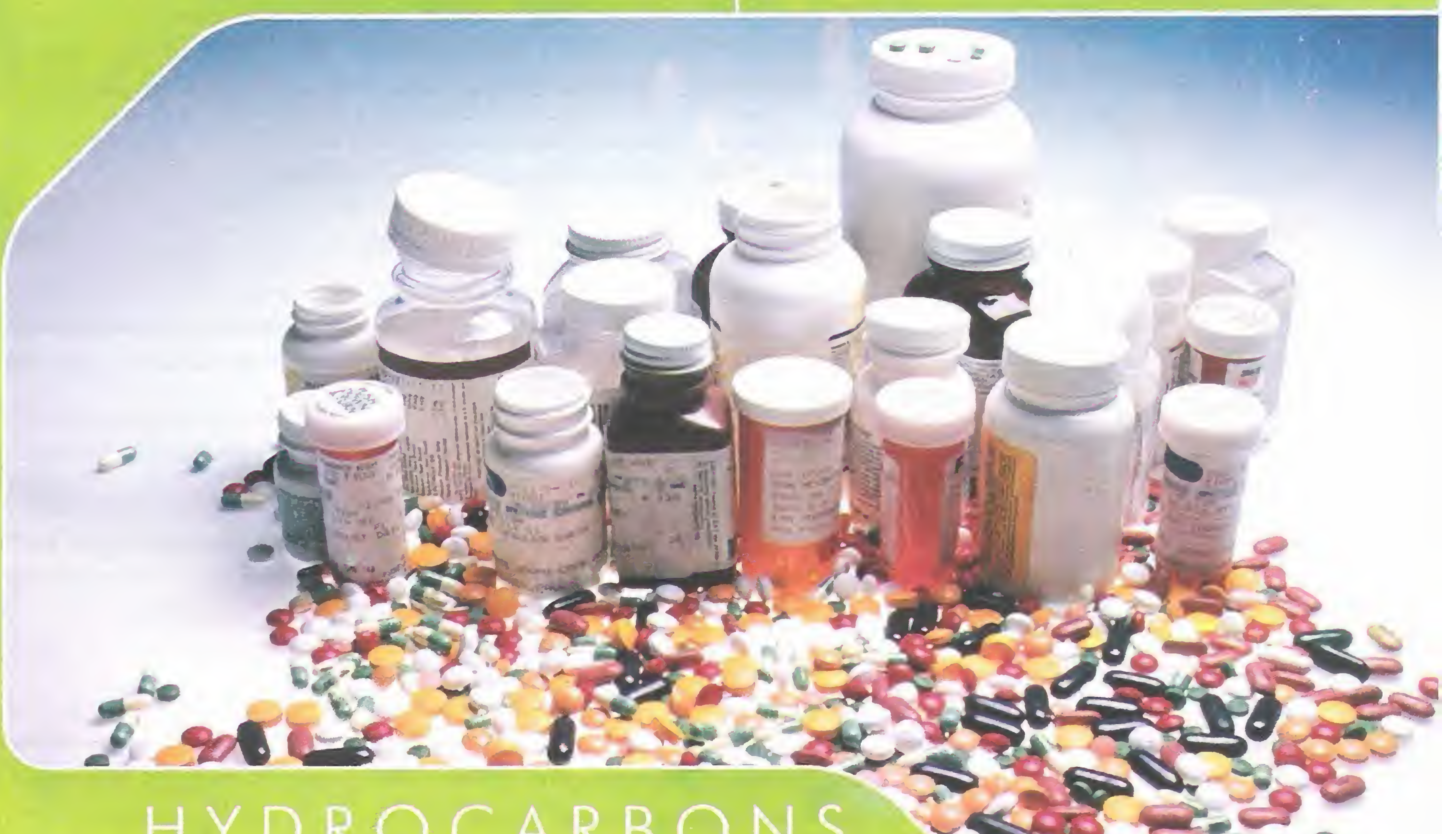
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1		11		17							20						14	9	25						

11 7 9 | 2 14 | 25 14 1 10 9 | 7 9 2 5 17 14 7 9 5 | 7 9

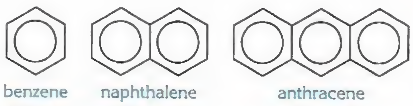
10 2 25 | 6 2 9 9 7 18 20 17 | 13 2 14 | 1 20 24 16 10 17 9 | 18 17 11 1 21 9 17

2 13 | 25 26 17 7 14 | 20 7 10 17 1 14 | 15 17 2 5 17 25 14 16

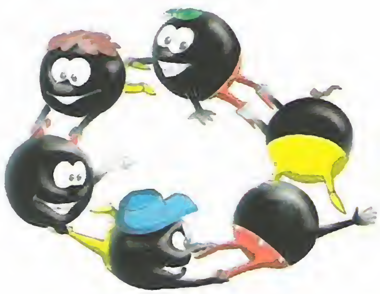
AROMATIC HYDROCARBONS



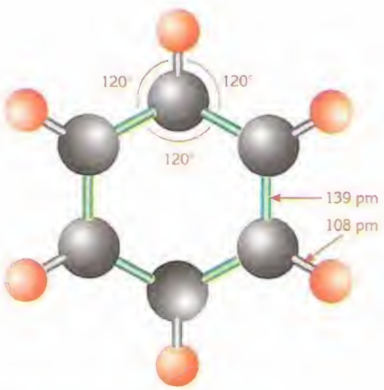
HYDROCARBONS



Molecules of benzene, naphthalene and anthracene have similar carbon structures to graphite.



Benzene structure



Molecular model of benzene

INTRODUCTION

Benzene and compounds having similar chemical properties to benzene are called ***aromatic*** compounds. The name "aromatic" is used because of the characteristic and pleasant odors of these compounds. Aromatic hydrocarbons are also known as arenes.

The simplest aromatic hydrocarbon is benzene. The most important source of arenes is coke, though some aromatic hydrocarbons may also be obtained from petroleum by cracking.

Although aromatic hydrocarbons are unsaturated, they have very different chemical properties to alkenes and alkynes. For example, benzene doesn't undergo an addition reaction with bromine despite having a double bond.

1. BENZENE AND ITS STRUCTURE

Benzene is the oldest known organic compound, firstly discovered by Michael Faraday in 1825. When he examined the white precipitates in gas tubes used for illumination, he discovered a new compound. He determined the empirical formula of this compound as CH and named it "bicarburet of hydrogen".

Later, Eilhardt Mitscherlich heated benzoic acid with limestone and synthesized benzene. He also found that benzene had the molecular formula C_6H_6.

$$C_6H_5COOH + CaO \xrightarrow{\text{heat}} \underset{\text{benzene}}{C_6H_6} + CaCO_3$$

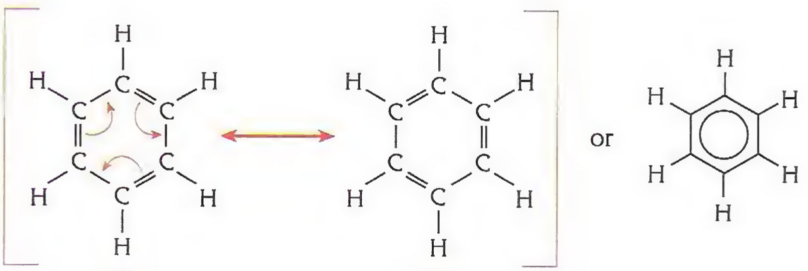
Benzene was considered unsaturated and a highly reactive compound at first because it has double bonds in its structure. However, benzene turned out to be unexpectedly inert and stable.

In 1865, the German chemist August Kekulé proposed a structure for benzene.

According to the structure Kekulé proposed, the benzene molecule had a regular hexagonal shape. The six carbon atoms are located at the corners and each bonded to two neighbours with one single and one double bond. The single and double bonds swap with each other around the ring. One hydrogen atom is bonded to each carbon atom.

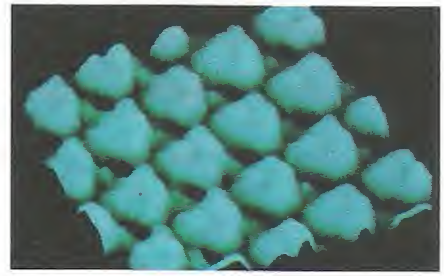
However, Kekulé's description is not enough to understand the structure of benzene. If the structure proposed by Kekulé was exact, the bond lengths of the $C = C$ and $C - C$ bonds would be different. But researches show that the benzene ring is a hexagon with equal internal angles of 120° and each carbon-carbon bond is equal with a length of 139 pm. Accordingly, there has to be another explanation of the benzene ring. This is the resonance structure. Resonance

theory tells us that we can place the double bonds in alternative positions. In fact, the double bonds may be between any two carbon atoms. Resonance structures are not in equilibrium, they are not the structures of real molecules. But they are the closest we can get if we are bound by the simple rules of valence and are very useful in helping us visualize the actual molecule as a mixture of two structures.



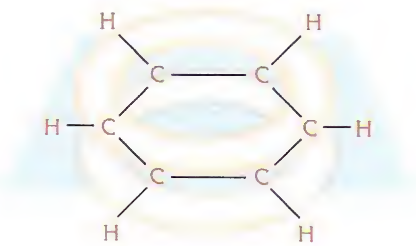
(a) (b)

The resonance structures of benzene



The picture of benzene molecules obtained by a scanning tunnelling microscope.

In the benzene molecule, each of the six carbon atoms undergoes sp^2 hybridization. Benzene has a planar shape and the carbon - carbon bond lengths are 139 pm. The six carbon ring is formed by the overlap of the sp^2 orbitals of the carbon atoms. The resulting p orbitals then overlap to form π bonds.

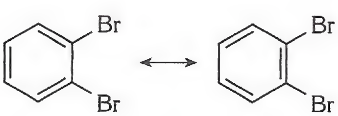
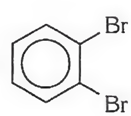


The model of the benzene molecule

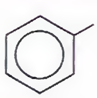
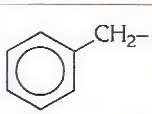
The planar benzene lies between these two pi orbital clouds. These π bonds make benzene very stable and explain why the carbon-carbon bonds are of equal length.

If the structure of benzene proposed by Kekulé were correct, there would be two different 1,2 – dibromobenzene compounds. In fact, there is only one 1,2–dibromobenzene.

This compound is shown as;

 the resonance structures, or as 

When a hydrogen is removed from an aromatic hydrocarbon an aryl group is formed, named as phenyl if the hydrogen is removed from benzene.

Formula	C_6H_5-	$C_6H_5-CH_2-$
Structure		
Name	phenyl	benzyl

READING — AUGUST FRIEDRICH KEKULÉ

August Friedrich Kekulé was a German scientist. He originally studied architecture at the University of Giessen.

It was here that he became interested in chemistry and so changed his course of study. He enrolled in a chemistry class under Justus von Liebig.

August Friedich Kekulé (1829–1896)

He became professor at Ghent and Bonn and studied various carbon compounds, especially benzene, proposing a carbon ring for its structure.

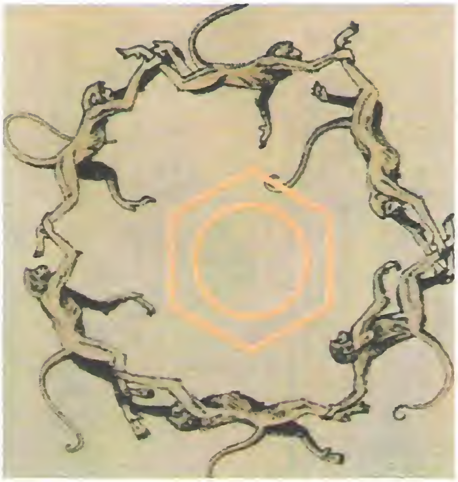
He said that he proposed the ring shape of the benzene molecule after dreaming of a snake biting its own tail.

He described his dream in a speech as follows;

"I turned my chair to the fire and dozed. The atoms were skipping before my eyes. This time the smaller groups kept to the background.

My mental eye, rendered more acute by the repeated visions of the same dream, could now distinguish larger structures of manifold conformations; long rows sometimes fitted together all twining and twisting in snake-like motion.

One of the snakes had swallowed the end of its own tail, and the form whirled mockingly before my eyes"



The representation of the Kekulé structure of benzene by six monkeys. Notice that the monkeys held by two hands use one leg and vice versa.

The stamp printed by the German government in the honor of Kekulé's discovery.

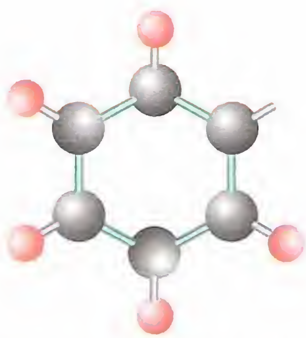
2. NOMENCLATURE OF AROMATIC COMPOUNDS

2.1. NOMENCLATURE OF MONOSUBSTITUTED BENZENE

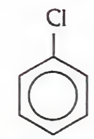
In the naming of monosubstituted benzenes, benzene is the parent name and the substituent is indicated by a prefix.

In the older naming system, the group attached to the benzene ring is considered to be attached to a phenyl group.

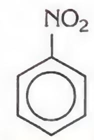
Some benzene derivatives have special names. Methylbenzene is usually called toluene, hydroxybenzene is known as phenol and aminobenzene is almost always called aniline.



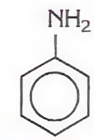
The molecular structure of phenyl (C_6H_5–) is formed by removing one H atom from the benzene (C_6H_6) molecule.



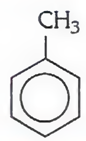
chlorobenzene
phenyl chloride



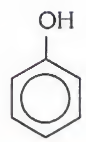
nitrobenzene



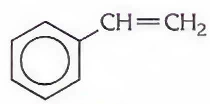
aminobenzene
phenyl amine
aniline



methylbenzene
phenyl methane
toluene



hydroxybenzene
phenol



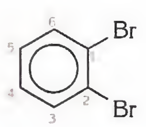
vinyl benzene
phenyl ethylene
Styrene

In the benzene molecule, all the carbon atoms are identical. So in monosubstituted benzene derivatives, there is no need to number the carbon atoms. Thus there is only one possible fluorobenzene structure, it makes no difference to which carbon atom the fluorine atom is attached.

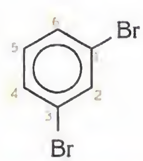
Fluorobenzene

2.2. NOMENCLATURE OF DISUBSTITUTED BENZENE

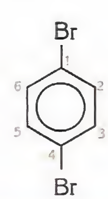
When two identical substituents are present, the number of each substituent is indicated by beginning from any of the substituents and going in the direction which gives the next substituent the lowest number possible.



1,2-dibromobenzene

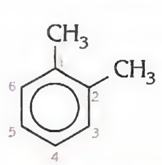


1,3-dibromobenzene

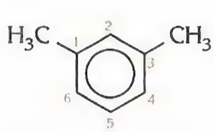


1,4-dibromobenzene

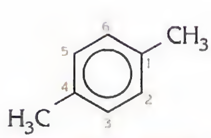
The dimethylbenzenes are known as XYLENES



1,2-dimethylbenzene
(not 1,6 dimethylbenzene)

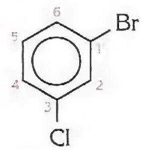


1,3-dimethylbenzene
(not 1,5 dimethylbenzene)

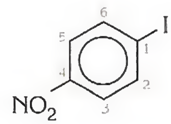


1,4-dimethylbenzene

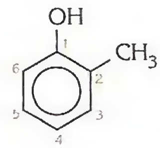
When the substituents are different; we number the ring beginning with the substituent first in the alphabet, and number in the direction that gives the next substituent the lowest number possible.



1–bromo–3–chlorobenzene

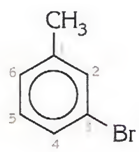


1–iodo–4–nitrobenzene

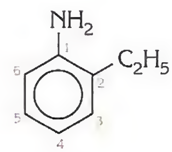


1–hydroxy–2–methylbenzene (cresol)

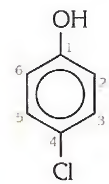
However, if the compounds are toluene, aniline, or phenol, the group that gives the compound its name (toluene - CH_3, aniline-NH_2, phenol - OH) is numbered first. So toluene, aniline and phenol are taken as the parent names.



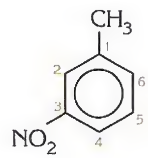
3–bromotoluene



2–ethylaniline



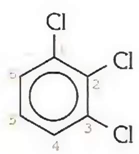
4–chlorophenol



3–nitrotoluene

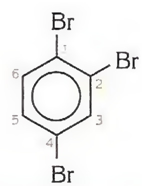
2.3. NOMENCLATURE OF TRI OR MORE SUBSTITUTED BENZENE DERIVATIVES

When three or more of the same substituents are present, numbering starts with the substituent that gives the smallest set of numbers.



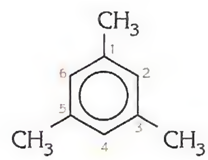
1,2,3–trichlorobenzene

(not: 1,5,6–trichlorobenzene)



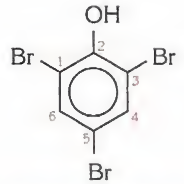
1,2,4–tribromobenzene

(not: 1,4,6–tribromobenzene)

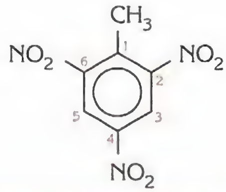


1,3,5–trimethylbenzene

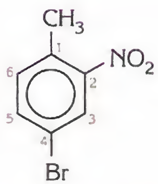
When two or more types of substituent are present they are written in alphabetical order. When there is a derivative of toluene, aniline or phenol, the substituent responsible for the parent name is assumed to be in position 1 and the other substituents are numbered as usual.



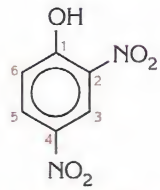
1,3,5–tribromo–2–hydroxybenzene
2, 4, 6–tribromophenol



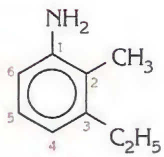
1–methyl–2,4,6–trinitrobenzene
2, 4, 6–trinitrotoluene



4–bromo–2–nitrotoluene



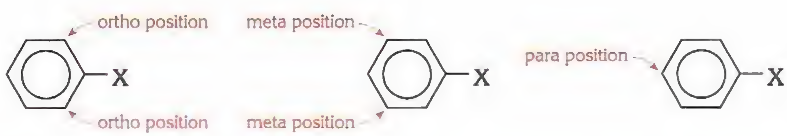
2,4–dinitrophenol



3–ethyl–2–methylaniline

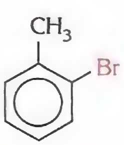
3. ISOMERISM IN BENZENE DERIVATIVES

Monosubstituted benzene derivatives do not exhibit isomerism. However, when two substituents are present, there are three possible isomers depending upon the relative positions of the substituents within the ring. These relative positions are indicated by the Latin words ortho, meta or para, or their initials:

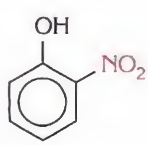


Ortho, meta and para positions according to the X atom or group that is bonded to the benzene ring.

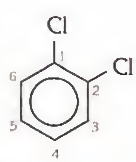
When the substituents are on neighbouring carbon atoms, (1,2–), they are in the ortho– position.



2–bromotoluene
o–bromotoluene



2–nitrophenol
o–nitrophenol



1,2–dichlorobenzene
ortho–dichlorobenzene
o–dichlorobenzene

4. PHYSICAL PROPERTIES OF BENZENE

Benzene is a colorless, poisonous liquid with a specific odor. It dissolves in organic solvents such as ether, alcohol, acetone and acetic acid. Benzene is also a good solvent for non-polar substances, it is used to dissolve fats, resins, rubber, iodine and sulfur. Its carbon content is high, therefore, when burned, it gives a sooty flame.

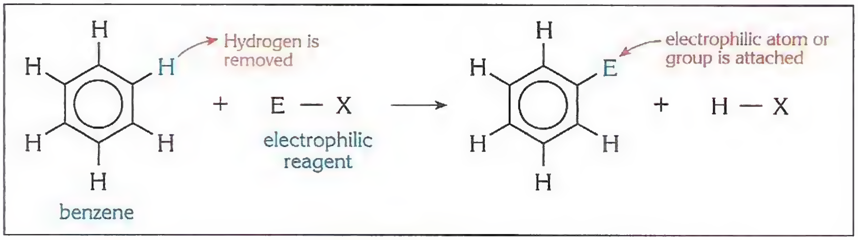
Benzene burns with a sooty flame.

5. CHEMICAL PROPERTIES AND REACTIONS OF BENZENE

Benzene is an unsaturated compound however its special structure makes it stable. So, unlike other unsaturated compounds, alkenes and alkynes, benzene primarily undergoes substitution reactions rather than addition reactions.

5.1. SUBSTITUTION REACTIONS

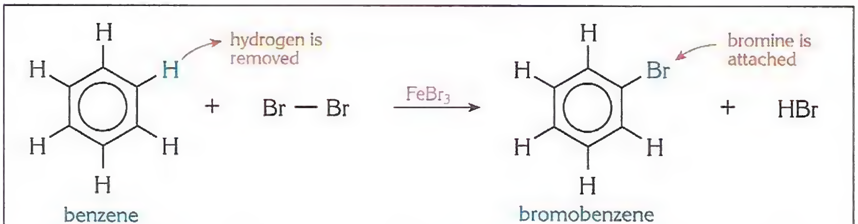
Substitution reactions occur between electrophilic reagents (electron-deficient) and the benzene ring which is electron-rich. Electrophiles attack the benzene ring, replacing one of the hydrogen atoms, this is known as a substitution reaction.

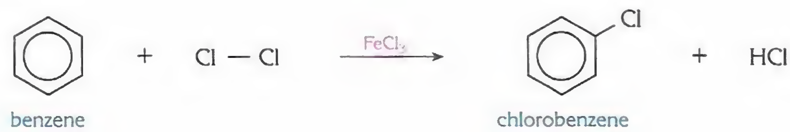


Benzene can undergo substitution reactions with halogens, HNO_3, alkyl halides (RX), and H_2SO_4.

Substitution Reactions with Halogens

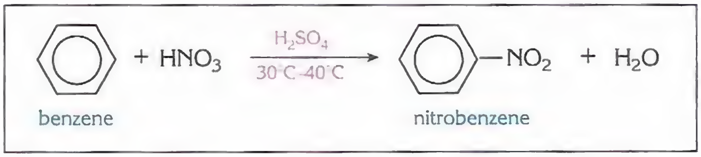
In the presence of a Lewis acid ($FeCl_3$ or $FeBr_3$) benzene undergoes substitution reactions with halogens giving good yields.





Substitution Reaction with HNO_3

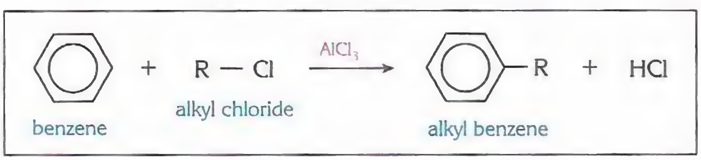
When benzene is reacted with a mixture of concentrated nitric acid and concentrated sulfuric acid, it yields nitrobenzene.

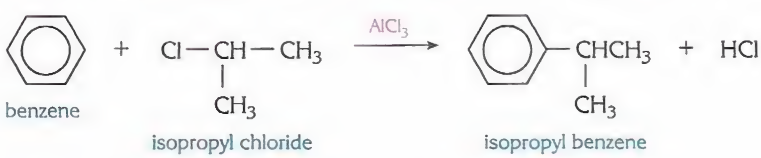


Substitution Reaction with Alkyl Halides

If benzene is reacted with an alkyl halide in the presence of $AlCl_3$ catalyst, alkyl benzenes are produced.

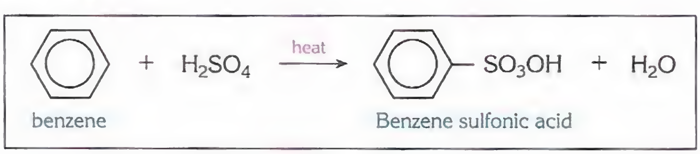
In 1877 a French chemist, Charles Friedel, and his American collaborator, James M. Crafts discovered this method for preparing alkyl benzenes. These reactions are now known as Friedel - Crafts reactions.





Substitution Reaction with H_2SO_4

If benzene reacts with hot, concentrated sulfuric acid solution, benzene sulfonic acid is produced.



Example 3

10.6 grams of ethylbenzene is obtained by the Friedel - Crafts method. How many moles of ethyl bromide were used in the reaction?

(C : 12, H : 1)

Solution

First, let us find the molecular weight of ethylbenzene.

$$M_{C_6H_5C_2H_5} = 8 \cdot 12 + 10 \cdot 1 = 106 \text{ g/mol}$$

$$n_{C_6H_5C_2H_5} = \frac{10.6 \text{ g}}{106 \text{ g/mol}} = 0.1 \text{ mol}$$

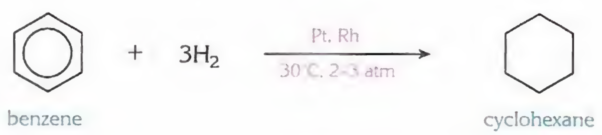
So according to the reaction below, this is also the number of moles of ethyl bromide used up.

Therefore, $n_{C_2H_5OH} = 0.1$ mole as well.

5.2. ADDITION REACTIONS

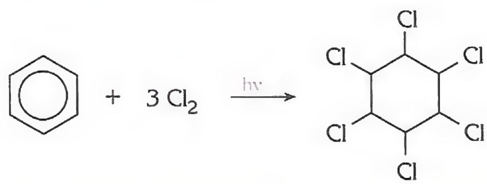
As well as substitution reactions, benzene can undergo addition reactions under certain conditions, although it is difficulty.

Benzene undergoes an addition reaction with hydrogen with a platinum/rhodium catalyst at 2-3 atm pressure and at 30°C.



If nickel is used as the catalyst, the reaction requires higher temperatures and pressures.

Under sunlight or ultraviolet rays chlorine reacts with benzene to yield hexachlorocyclohexane



6. OCCURRENCE AND PREPARATION OF BENZENE

Coal tar is the main natural source of benzene and other aromatic hydrocarbons. Coal tar contains benzene, toluene, xylene, phenol, naphthalene and anthracene.

Heating of coal tar.

Benzene can also be produced from petroleum hydrocarbons by aromatization. Alkanes can be dehydrogenated to produce benzene and its derivatives by heating them over catalysts.

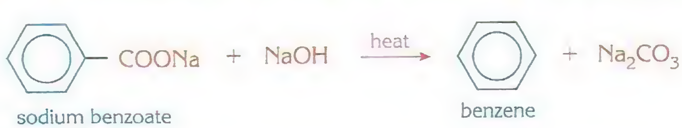
Three methods to prepare benzene are :

6.1. TRIMERIZATION OF ACETYLENE

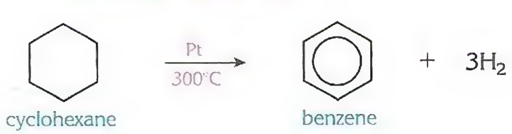
Acetylene is trimerized under high pressures and temperatures.

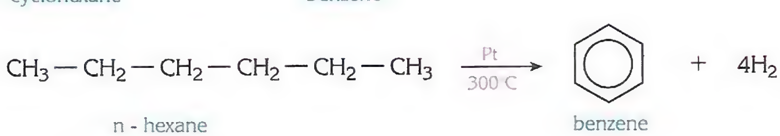
$$\underset{\text{acetylene}}{3C_2H_2} \xrightarrow[\text{pressure}]{500\text{–}600^\circ C} \underset{\text{benzene}}{C_6H_6}$$

6.2. DECARBOXYLATION OF SODIUM BENZOATE



6.3. DEHYDROGENATION OF HEXANE AND CYCLOHEXANE

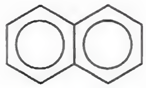


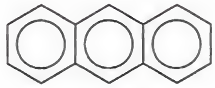


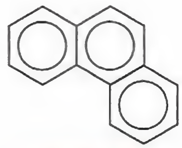
7. OTHER AROMATIC HYDROCARBONS (POLYCYCLIC AROMATIC HYDROCARBONS)

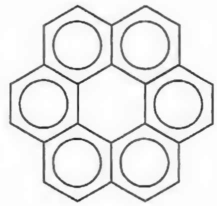
Two or more benzene rings may be fused together to form polycyclic aromatic hydrocarbons.

The simplest member of this family is naphthalene. Anthracene and phenanthrene are isomers with the molecular formula $C_{14}H_{10}$. Anthracene consists of three rings fused together in a straight line, and phenanthrene has three rings fused together with an angular geometry.


naphthalene


anthracene


phenanthrene


coronene

7.1. NAPHTHALENE

Two benzene rings are fused together to form naphtalene. Its melting point is 80°C and its boiling point is 218°C. Naphthalene is a colorless, crystalline compound which sublimes easily. It is insoluble in water but soluble in organic solvents. It has a sharp, aromatic odor and is used to protect clothes from moths and to dispel the bad odors in bathrooms.

7.2. ANTHRACENE

Anthracene is formed by fusing three benzene rings together in a linear geometry. Its melting point is 216°C.

It is a colorless, crystalline compound used in the production of paints.

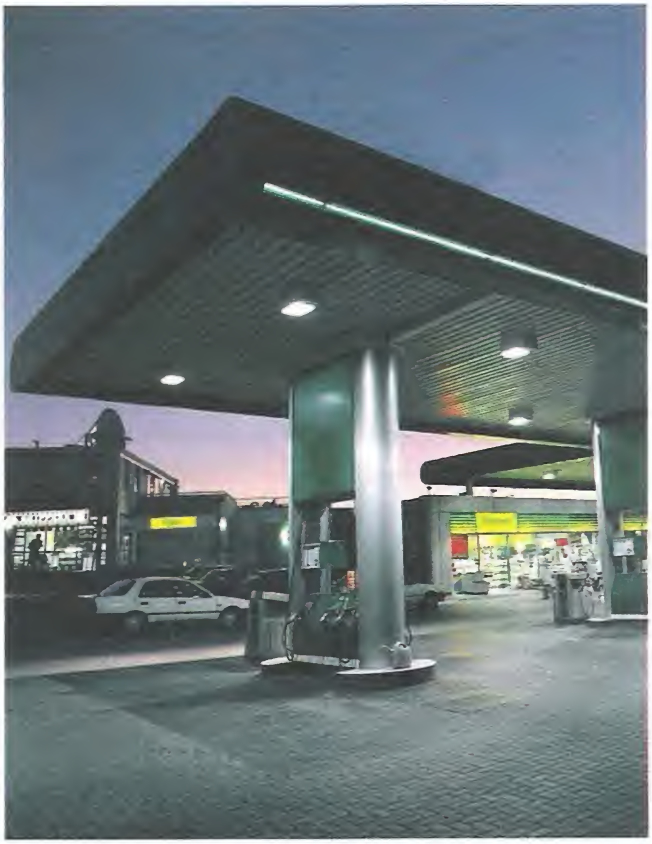
READING PETROL (GASOLINE)

Petrol is a petroleum liquid mixture consisting of hydrocarbons. It is used as fuel in car engines. The word gasoline is used in America to refer this mixture.

The majority of hydrocarbons in petrol are aliphatic compounds. Most hydrocarbon chains in gasoline extend from 6 to 12 carbon atoms. Typical gasoline also contains aromatic and other unsaturated aliphatic hydrocarbons, ether, amines, and sulfoxides.

Octane Rating

Gasoline must burn gently in the engine without premature detonation.



The octane rating is the criterion of how resistant the gasoline is to detonation before the proper time. It is measured relative to a mixture of isooctane and n–heptane.

A 75 octane gasoline has the same detonation resistance as a mixture of 75% isooctane and 25% n-heptane. 87 octane is the standard rating for "normal" gasoline and has the same detonation resistance as a mixture of 87% isooctane and 13% heptane.

As gasoline mixtures have a tendency to explode prematurely, lead additives were first mixed with fuel in the 1920's up until the 1980's. However this caused very serious environmental problems and different additives are now used, such as ethers, aromatics and alcohols.

Petrodiesel

Petrodiesel is obtained from the fractional distillation of crude oil between 250°C and 350°C under atmospheric pressure. Diesel fuel contains mineral compounds and sulfur.

Diesel fuel is a very complex mixture of thousands of individual compounds most with carbon numbers between 10 and 22. Most of these compounds belong to the aliphatic, aromatic or naphthalic classes of compounds.

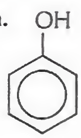
Diesel contains about 18% more energy than gasoline.

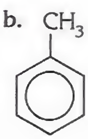
Today, diesel engines are used worlwide for transportation, manufacturing, power generation and farming.

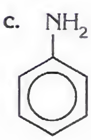
SUPPLEMENTARY QUESTIONS

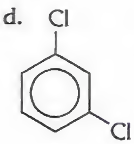
1. Explain the bonding in benzene.

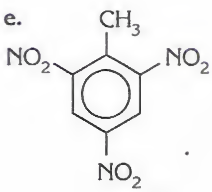
2. Name the following compounds.

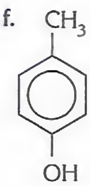
a. 

b. 

c. 

d. 

e. 

f. 

3. Draw the structural formulae of the compounds below

a. nitrobenzene

b. m–chlorophenol

c. p - dichlorobenzene

d. o - ethylnitrobenzene

e. 1 - bromo - 2 - methyl - 3 - phenylcyclohexane

f. o - chloro - phenylpropane

g. 1,3 - dichloro - 5 - isopropylbenzene

h. triphenylmethane

4. Draw the structural formulae and give the names of all the possible isomers of the aromatic C_8H_{10} compounds. (there are four of them)

5. Write the combustion reactions for the following compounds

a. Benzene b. Toluene

c. Naphthalene d. Anthracene

6. Which of the reactions of benzene;

I. Nitration

II. Sulfonation

III. Bromination

IV. Alkylation

are redox reactions? Explain

7. Starting from benzene obtain;

a. tert - butylbenzene

b. allyl benzene

8. Propose a method to check whether a compound is benzene, hexene or hexane?

9. Find the volume of hydrogen (at STP) necessary to saturate 15.6 grams of benzene?

10. 750 ml NaOH solution is reacted with excess sodium benzoate to produce 23.4 grams of benzene.

What is the molarity of the NaOH solution?

11. By using the Friedel - Crafts method, 26.5 grams of alkyl benzene is produced from 0.25 mol of benzene.

Determine the structure of the produced benzene derivative.

12. Find the mass of benzene that is obtained from the acetylene that takes up a volume of 13.44 L at STP. The yield of the reaction is 80%.

1. For benzene;

   I. It is an aromatic compound.

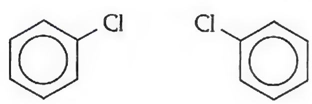
   II. Its empirical formula is CH.

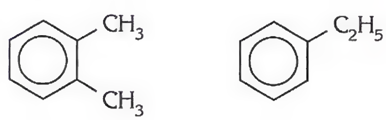
   III. It contains 3 π and 12 σ bonds.

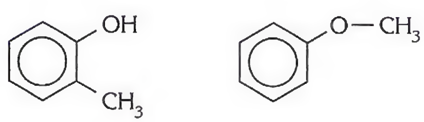
   Which of the above statements is/are correct?

   A) I only B) II only C) I and III D) II and III E) I, II and III

2. Which of the following pairs of compounds are isomers?

   I. 

   II. 

   III. 

   A) I only B) I and II C) I and III D) II and III E) I, II and III

3. All of the following react with benzene except:

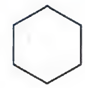
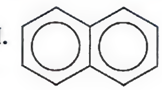
   A) Water

   B) Nitric acid

   C) Bromine

   D) Sulfuric acid

   E) Methyl chloride

4. I.  II.  III. 

   Which of the above compounds is/are aromatic?

   A) I only B) II only C) I and II D) II and III E) I, II and III

5. Which of the following is correct for the benzene molecule?

   A) It contains 12 hydrogen atoms.

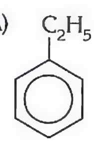
   B) It is unsaturated.

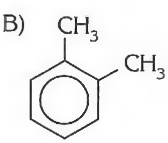
   C) The carbon-carbon bonds are single.

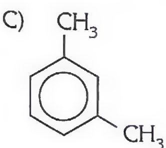
   D) The carbon-carbon bonds are double.

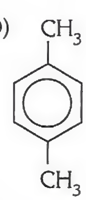
   E) It has an acyclic structure.

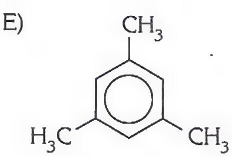
6. All of the followings are isomers of each other except:

   A) 

   B) 

   C) 

   D) 

   E) 

7. I. Its molecular formula is $C_{10}H_8$.

   II. Hydrogen can be added to it at room temperature.

   III. It is an aliphatic hydrocarbon.

   Which of the above statements is/are correct for naphthalene?

   A) I only B) II only C) III only D) I and II E) I and III

WORD SEARCH

Try to find the hidden words given below.

ANTHRACENE
ARENE
AROMATIC
BENZENE
HEXAGONAL
NAPHTHALENE
NONPOLAR
PHENOL
RING
STYRENE
SUBSTITUTON
TOLUENE

E	J	Z	T	C	U	G	C	O	Z	A	S	B	B	F	B	X	J
M	N	H	B	Y	U	I	N	H	E	U	A	O	A	U	E	P	Y
U	A	E	O	E	T	X	E	I	B	E	T	A	J	F	N	Q	L
E	V	X	C	A	P	X	X	S	R	E	N	A	D	I	Z	V	X
H	T	C	M	A	A	T	T	V	Z	E	L	K	U	L	E	B	P
G	A	O	O	G	R	I	R	N	F	I	P	I	G	Z	N	M	T
F	R	F	O	R	T	H	R	A	L	O	P	N	O	N	E	O	D
A	P	N	F	U	G	U	T	N	X	E	J	E	D	E	L	P	C
X	A	N	T	S	I	P	K	N	H	A	L	N	I	U	B	D	S
L	A	I	L	I	X	O	Q	Q	A	P	U	Z	E	M	H	Z	T
V	O	W	U	X	Z	A	U	X	K	X	X	N	I	Y	T	F	Y
N	I	O	P	Y	L	L	O	M	Y	U	E	X	L	H	N	S	R
E	O	J	O	Q	L	G	O	B	K	V	N	I	D	H	S	L	E
N	A	P	H	T	H	A	L	E	N	E	Z	L	K	D	A	E	N
X	X	E	U	Z	C	O	B	F	N	D	D	W	A	O	B	T	E
P	K	D	S	I	O	X	A	B	U	D	A	C	P	F	L	A	N
P	H	E	N	O	L	S	K	Z	J	F	B	D	Z	H	G	K	A
A	R	E	N	E	B	Q	H	D	N	A	F	L	N	P	Y	A	U

FALLEN PHRASES (Aromatics)

Letters of the words are mixed in vertically. Place the letters in the correct box and get the message.

■	■	■	■		H		■	■	■	■
■				P			S		■	■
■			O			T			■	■
	Y			O				B		
		■			N					■

						Z				
	S	D	M	M	C	E	R	T		
H	A	R	B	T	L	E	I	C	O	
I	S	I	R	E	A	A	E	N	E	N

GLOSSARY
ANSWERS
INDEX

HYDROCARBONS

GLOSSARY

Acetic acid : Colorless liquid with an irritating odor, CH_3COOH.

Acetylene : The first member of alkynes is acetylene or ethyne (C_2H_2).

Acetylenes : The common name for alkynes.

Acid anhydrides : A substance formed by the elimination of one molecule of water from two molecules of an acid.

Acidic strength : The strength of an acid is measured by the value of its dissociation constant.

Addition reaction : An organic reaction in which the molecule of one reactant adds to a double or triple bond of another reactant.

Aliphatic : A hydrocarbon having an open chain structure.

Alkadienes : Alkenes which have two double bonds in their structure.

Alkane : An open–chain hydrocarbon in which all carbon–carbon bonds are single bonds. The alkanes conform to general formula C_nH_{2n+2}

Alkapolyenes : Alkenes which have more than 2 double bonds.

Alkene : Hydrocarbons whose molecules have one or more double bonds.

Alkyne : Is a hydrocarbon whose molecules have one or more triple bonds.

Amino acids : A large class of organic compounds containing both the carboxyl, COOH and the NH_2 group.

Aromatic hydrocarbons : An organic compound whose molecules have the benzene ring system.

Aryl group : When a hydrogen atom is removed from a hydrocarbon of the benzene series, the result is an aryl group.

Carboxylic acid : Organic compounds containing one or more carboxyl (COOH) groups.

Chirality : A term which may be applied to any asymmetric object or molecule.

Cis isomer : A molecule which has two substituents on the same side of the double bond.

Combustion : The rapid, high temperature oxidation of fuels, converting carbon to carbon dioxide and hydrogen to water vapor.

Cracking reactions : An industrial process in which large molecules are broken down into smaller ones.

Dehalogenation : The elimination of the elements of a hydrogen halide.

Dehydration : The elimination of water.

Dimerization : A compound formed by the addition polymerization of two molecules of a monomer.

Empirical formula : A chemical formula that uses the smallest whole-number subscripts to give the proportions of the atoms of the different elements present.

Enantiomers : Stereoisomers whose molecular structures are related as an object to its mirror image but that can't be superimposed.

Grignard reagent : An organomagnesium compound, RMgX, where R can be an alkyl or an aryl radical and X is a halogen atom.

Homologous series : A series of compounds that may be considered to be derived from the first member by the successive addition of a $-CH_2-$ unit.

Hydrocarbon : An organic compound whose molecules consist entirely of carbon and hydrogen atoms.

Hydrolysis : A term is used to signify reactions involving water.

Hydroxy acid : Carboxylic acids that contains (OH) hydroxyl groups.

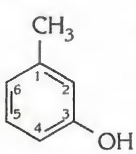
Inorganic compound : Any compound other than organic compounds.

Isomerism : Compounds possessing the same composition and the same molecular weight, but differing in their chemical structure. Isomers have different physical properties.

Keto acids : Carboxylic acids that have an extra $(-\overset{\overset{\displaystyle O}{\|}}{C}-)$ carboxyl group in their structure.

Markovnikov's rule : When an unsymmetrical reagent adds to the carbon–carbon double bond of an unsymmetrical double bond, the hydrogen adds to the carbon of the double bond that has the greater number of hydrogens on it.

Meta :



The CH_3 and OH groups are said to be in the meta position relative to each other.

Molecular formula : A chemical formula that gives the actual composition of a molecule.

Neutralization reaction : The destruction of an acid by a base or vice versa.

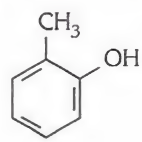
Optical isomer : Stereoisomers other than geometric (cis-trans) isomers that include substances that can rotate the plane of plane polarized light.

Optically active : Having the ability to rotate the plane of plane polarized light.

Organic chemistry : Organic chemistry is the study of the compounds of carbon whether they are isolated from natural sources or synthesized in the laboratory.

Organic compound : An organic compound is any of a large class of chemical compounds of which the molecules contain C, H. Some organic compounds may also contain O, N, S, P as well as C and H.

Ortho :

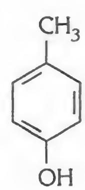


The CH_3 and OH groups are said to be in the ortho position relative to each other.

Oxidation reaction : Any process by which the proportion of the electronegative constituents in a compound is increased.

Oxyacids : Organic acids that have the hydroxyl group with the carboxylic group.

Para :



CH_3 and OH groups are said to be in the para position relative to each other.

Polycyclic aromatic hydrocarbon : Two or more benzene rings connected together form polycyclic aromatic hydrocarbons.

Polymer : A polymer is a long, repeating chain of atoms, formed through the linkage of many identical molecules called monomers.

Polymerization : The term includes any process that results in the formation of large molecules, consisting of repeated structural units.

Polymerization reaction : The term includes any process that results in the formation of macromolecules consisting of repeating structures.

Resonance : A concept in which the actual structure of a molecule or polyatomic ion is represented as a composite or average of two or more Lewis structures, which are called the resonance or contributing structures (and none of which actually exist).

Saturated compound : A compound whose molecules have only single bonds.

Sigma (σ) bond : A bond formed by the head to head overlap of two atomic orbitals and in which electron density becomes concentrated along and around an imaginary line joining the two nuclei.

Structural formula : A chemical formula that shows how the atoms of a molecule or polyatomic ion are arranged and the kinds of bonds (single, double on triple).

Substitution reaction : A reaction in which an atom or a group of atoms is substituted for another atom or group of atoms in a molecule.

Tautomerism : Special case of structural isomerism in which two isomers are directly interconvertible, the reversibility of the change is due to mobility of a group on atom, which can move from one position to another in the molecule, often with the rearrangement of a double bond.

Trans isomer : Isomers which the substituents are on opposite sides of the double bond.

Unsaturated compound : A hydrocarbon that contains one or more carbon – carbon multiple bonds,

Valency concept : Valency theory is based on the concept that elements tend to gain, lose or share electrons in order to complete their outer electron shell.

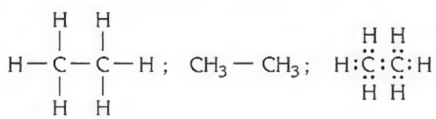
Vulcanization : The process of conferring more cross linking upon a rubber and so altering its structure so it becomes less plastic and sticky, more resistant to swelling by organic liquids and more elastic.

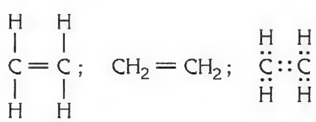
Wurtz synthesis : Alkyl halides react with sodium in dry ether solution to give hydrocarbons.

ANSWERS

SUPPLEMENTARY QUESTIONS

INTRODUCTION TO ORGANIC CHEMISTRY

6. a. 

c. 

10. CH_2

11. C_3H_4

12. CH_3

13. C : 40%, H : 6.7%, O : 53.3%

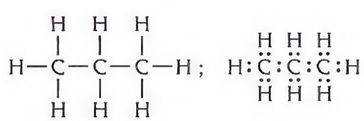
14. $C_6H_{12}O_6$

15. $C_4H_8O_2$

16. $C_{15}H_{30}$

ALKANES

1. C_nH_{2n+2}

2. C_3H_8; 

3. 72 g/mol

4. $C_{10}H_{22}$

5. C_2H_6

6. CH_4

7. Methane, ethane, propane, butane, pentane, hexane, heptane, octane, nonane, decane

8. a. 2–methylbutane,

   b. 2–methylpentane

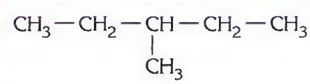
   c. 2,3–dimethylhexane

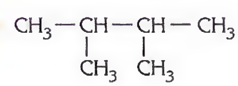
   d. 1–bromo–2–methylpropane

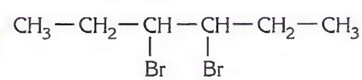
   e. 2,3–dimethylpentane

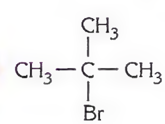
   f. 3,4–dimethylhexane

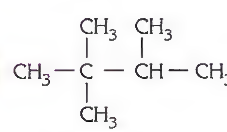
   g. 3–chloro–4–methylhexane

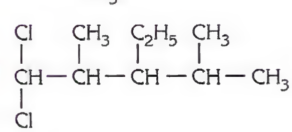
9. a. 

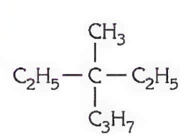
   b. 

   c. 

   d. 

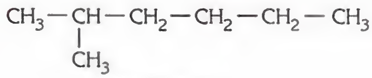
   e. 

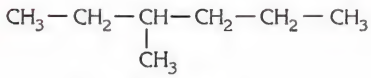
   f. 

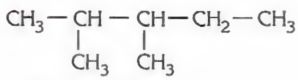
10.  3 – ethyl – 3 – methyl hexane

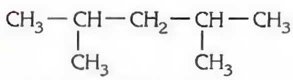
18.

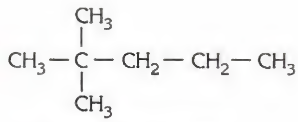
a. $CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$
n – heptane

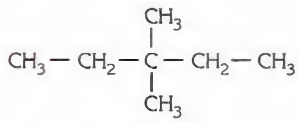
b. 
2 – methylhexane

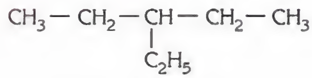
c. 
3 – methylhexane

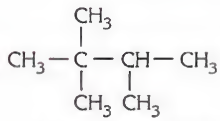
d. 
2,3 – dimethylpentane

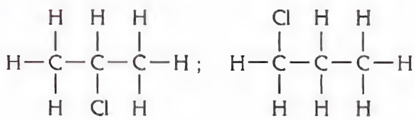
e. 
2,4 – dimethylpentane

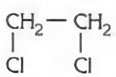
f. 
2,2 – dimethylpentane

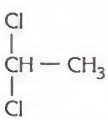
g. 
3,3 – dimethylpentane

h. 
3 – ethylpentane

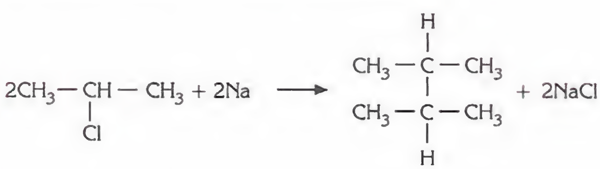
i. 
2,2,3 – trimethylbutane

19. 

20. 
1,2 – dichloroethane


1,1 – dichloroethane

21.

a. 

22.

a. $2C_2H_5Cl + 2Na \longrightarrow C_4H_{10} + 2NaCl$

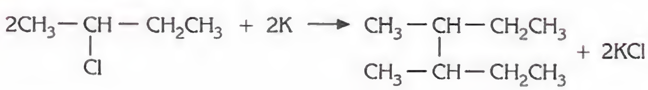
b. $C_4H_9MgCl + HOH \longrightarrow C_4H_{10} + Mg(OH)Cl$

c. $C_4H_9-COONa + NaOH \xrightarrow{heat} C_4H_{10} + Na_2CO_3$

23.

a. $2CH_3CH_2CH_2Br + 2Na \longrightarrow C_6H_{14} + 2NaBr$

b. $CH_3CH_2MgBr + HBr \longrightarrow C_2H_6 + MgBr_2$

c. 

24. 1.6 g.

25. $$CH_3-\underset{\underset{\displaystyle Cl}{|}}{C}HCH_2CH_3 + CH_3Cl + 2\,Na \longrightarrow CH_3-\underset{\underset{\displaystyle CH_3}{|}}{C}H-CH_2CH_3 + 2NaCl$$

2 – chlorobutane chloromethane 2 – methylbutane

26. a. 2 – chloro – 3,4 – dimethylhexane and chloroethane
b. 2 – chlorobutane and 2 – chloro – 3 – methylpentane
c. 1 – chloro – 2,3, 4 – trimethylhexane and chloromethane

28. 86 g/mol, 2,3 – dimethylbutane

29. $$C_2H_6 + HNO_3 \xrightarrow{t} C_2H_5-NO_2 + H_2O$$

nitroethane

30. 3.6 g

31. 1820 L

32. C_5H_{10} (cyclopentane)

33. a. 0.5 mol
b. 11.2 L
c. 78.4 L
d. 54 g

34. 1996 g

35. 35%

36. 28 g

37. 66.7%

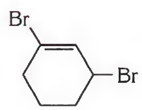
39. 22.4 L

40. 2 L of propane and 3 L of butane

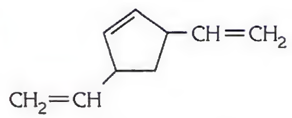
42. a. methylcyclopentane
b. 1–ethyl–4–methylcyclohexane
c. 1–chloro–3–ethylcyclobutane
d. 2–cyclopentylbutane
e. 2–cyclohexyl–2–methylbutane
f. dicyclopropylchloromethane

1. a. 2–methyl–1–butene,
   c. 3–chlorocyclopentene
   e. 3,3–dimethyl–1–pentene
   g. 3–ethylcyclopentene
   i. 2,3–dichloro–1,3–butadiene
   k. 1–chloro–2,3–diethyl–2–pentene

2. a. $\underset{\displaystyle Cl}{\underset{|}{CH}}=\underset{\displaystyle Cl}{\underset{|}{CH}}$

   c. 

   e. $CH_2=CH-CH=CH-CH_3$

   g. 

   i. $CH_3-CH_2-\underset{\displaystyle CH_3}{\underset{|}{C}}=\underset{\displaystyle C_2H_5}{\underset{|}{C}}-CH_2-CH_2-CH_2-CH_3$

   k. $CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}}=\underset{\displaystyle CH_3}{\underset{|}{C}}-\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle Br}{\underset{|}{C}}}}-CH_2-CH_3$

4. C_3H_4

5. C_4H_8

6. a. $CH_3-CH=CH_2 + H_2 \longrightarrow CH_3-CH_2-CH_3$

   b. $CH_3-CH=CH_2 + Br_2 \longrightarrow CH_3-\underset{\displaystyle Br}{\underset{|}{CH}}-\underset{\displaystyle Br}{\underset{|}{CH_2}}$

   c. $CH_3-CH=CH_2 + HBr \longrightarrow CH_3-\underset{\displaystyle Br}{\underset{|}{CH}}-CH_3$

   d. $CH_3-CH=CH_2 + H_2O \longrightarrow CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_3$

7. 50%

8. 24 g

9. 37.5 g

10. 8.05%

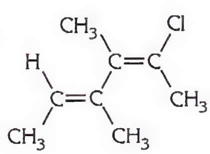
11. a. $CH_2{=}CH-CH_2CH_3 + HCl \longrightarrow CH_3-\underset{\displaystyle Cl}{\underset{|}{CH}}-CH_2-CH_3$

c. $CH_3-\underset{\displaystyle Cl}{\underset{|}{C}}{=}CH-CH_3 + HI \longrightarrow CH_3-\overset{\displaystyle I}{\overset{|}{\underset{\displaystyle Cl}{\underset{|}{C}}}}-CH_2-CH_3$

12. a. $2C_3H_6 + 9O_2 \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O}$

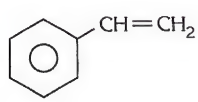
c. $CH_3-CH{=}CH_2 + HCl \longrightarrow CH_3-\underset{\displaystyle Cl}{\underset{|}{CH}}-CH_3$

2 – chloropropane

e.  $+ 2Br_2 \longrightarrow CH_3-\overset{\displaystyle Br}{\overset{|}{\underset{\displaystyle H}{\underset{|}{C}}}}-\overset{\displaystyle Br}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle Br}{\underset{|}{C}}}}-\overset{\displaystyle Cl}{\overset{|}{\underset{\displaystyle Br}{\underset{|}{C}}}}-CH_3$

2, 3, 4, 5 – tetrabromo – 2 – chloro – 3,4 – dimethylhexane

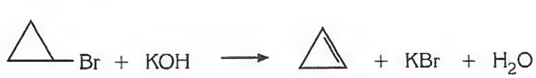
g. $3C_2H_4 + 2KMnO_4 + 4H_2O \longrightarrow 3\underset{\displaystyle OH}{\underset{|}{CH_2}}-\underset{\displaystyle OH}{\underset{|}{CH_2}} + 2MnO_2 + 2KOH$

13. a. $\overset{\displaystyle F}{\overset{|}{\underset{\displaystyle F}{\underset{|}{C}}}}{=}\overset{\displaystyle F}{\overset{|}{\underset{\displaystyle F}{\underset{|}{C}}}}$ c.  e. $CH_2{=}\underset{\displaystyle CH_3}{\underset{|}{C}}-CH_3$

15. a. $CH_2{=}CH_2$; ethylene

c. $CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}}{=}\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}$; 2,3 – dimethyl – 2 – butene

16. a. $CH_3-CH_2-CH_2-CH_2Cl + KOH \longrightarrow CH_3-CH_2-CH{=}CH_2 + KCl + H_2O$

c. 

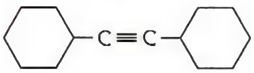
18. a. 9.8 g b. 140 g

ALKYNES

1. $CH \equiv CH$

2. C_4H_6

4. a. acetylene (ethyne)
   c. 4–bromo–3–methyl–1–butyne
   e. 4,4–dichloro–3,3–dimethyl–1–pentyne

5. a. $CH_3-C \equiv C-CH_2CH_3$
   c. $CH \equiv C-CH(Cl)-CH_3$
   e. 

9. C_3H_4

10. 38.6 g

11. 2.6 g.

14. a. C_5H_8
    b. 186.7 L
    c. 18 g

15. a. C_4H_6
    b. 8/11

16. C_2H_2

17. C_3H_4

18. 6.72 L

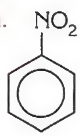
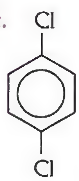
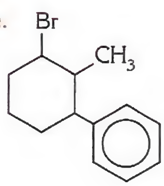
19. 1 – butyne, its mass is 16.2 grams.

20. 26.7 L

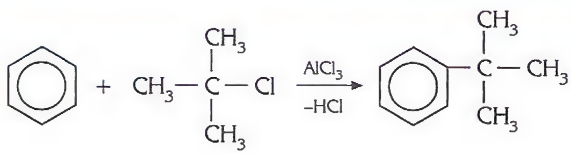
22. a. $2C_2H_2 + 5O_2 \longrightarrow 4\,CO_2 + 2\,H_2O$
    c. $CH_3-C \equiv CH + AgNO_3 \xrightarrow{NH_3} CH_3-CH \equiv CAg\downarrow + NH_4NO_3$

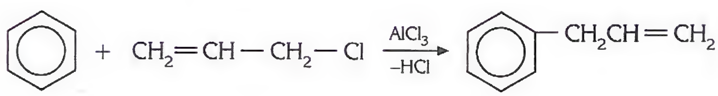
AROMATICS

2. a. phenol
   c. aniline
   e. 2, 4, 6 – trinitrotoluene

3. a. 
   c. 
   e. 

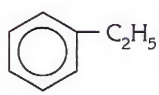
5. a. $2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
   b. $C_7H_8 + 9O_2 \rightarrow 7CO_2 + 4H_2O$
   c. $C_{10}H_8 + 12O_2 \rightarrow 10CO_2 + 4H_2O$
   d. $2C_{14}H_{10} + 33O_2 \rightarrow 28CO_2 + 10H_2O$

7. a. 

   b. 

9. 13.44 L

10. 0.4 M

11. 

12. 12.48 g

MULTIPLE CHOICE

INTRODUCTION TO ORGANIC CHEMISTRY

1. D	4. B	7. E	10. D
2. B	5. E	8. D	
3. E	6. E	9. D	

ALKANES

1. D	6. A	11. E	16. A
2. C	7. E	12. B	17. A
3. D	8. A	13. B	18. E
4. E	9. C	14. C	
5. E	10. E	15. E	

ALKENES

1. D	8. D	15. B	22. B
2. B	9. C	16. C	23. D
3. D	10. E	17. D	24. E
4. B	11. E	18. C	25. D
5. D	12. A	19. C	
6. D	13. C	20. E	
7. E	14. E	21. D	

ALKYNES

1. A	5. E	9. E	13. E
2. D	6. D	10. A	
3. A	7. D	11. B	
4. C	8. A	12. C	

AROMATIC

1. E	3. A	5. B	7. A
2. D	4. D	6. E	

PUZZLE

INTRODUCTION TO ORGANIC CHEMISTRY

DOUBLE PUZZLE

C A R B O N

O R G A N I C

C A T A L Y S T S

S T R U C T U R A L

E M P I R I C A L

M O L E C U L A R

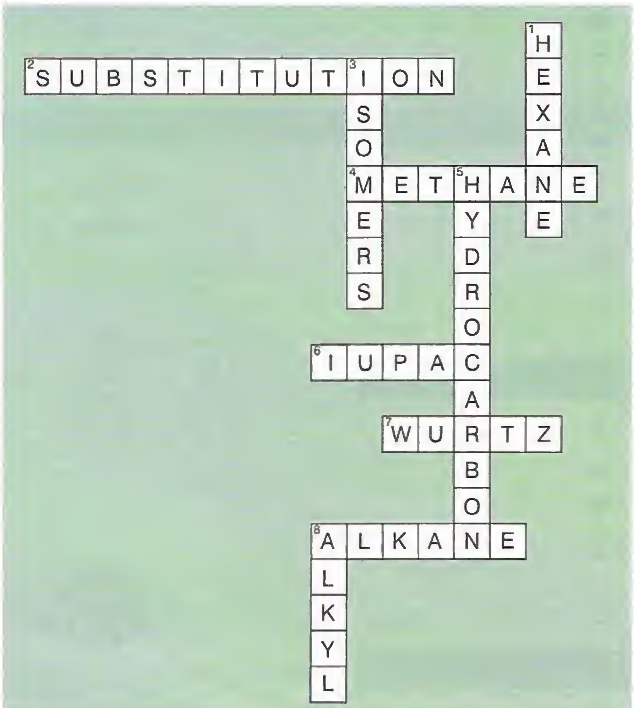
F O U R

Secret Message

PETROLEUM	AND	COAL	ARE	TWO
LARGE	RESERVOIRS	OF	ORGANIC	
MATERIAL	FROM	WHICH	SIMPLE	
ORGANIC	COMPOUNDS	CAN	BE	
	OBTAINED			

ALKANES

CRISS - CROSS PUZZLE



WORD SEARCH

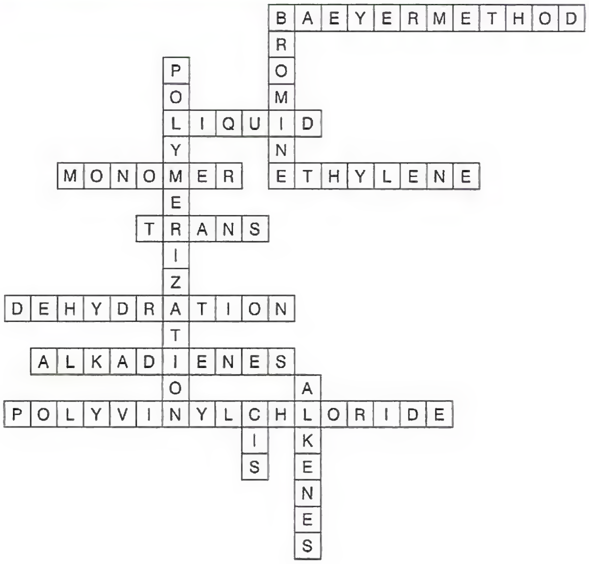
N	Z	S	N	I	F	R	P	G	S	G	N	U	O	K
Z	O	A	I	R	S	A	C	U	X	R	O	Q	N	G
T	M	I	C	G	R	O	O	J	E	I	B	A	U	Q
J	L	U	T	A	M	G	M	N	K	G	R	A	U	X
Y	I	Q	F	U	O	A	A	E	O	N	A	E	P	S
U	L	F	G	L	T	K	B	Z	R	A	C	N	F	P
N	I	D	O	G	L	I	G	O	S	R	O	A	P	X
N	I	M	P	A	S	N	T	E	N	D	R	T	W	W
B	O	J	S	C	D	A	L	S	N	D	D	U	U	E
H	G	N	I	K	C	A	R	C	B	A	Y	B	R	H
C	A	P	U	I	U	A	N	W	X	U	H	E	T	A
P	E	T	R	O	L	E	U	M	T	C	S	T	Z	J
N	M	Q	N	K	C	A	R	B	O	N	V	L	E	J
V	S	L	Y	N	A	K	Y	R	Z	L	F	R	T	M
Z	C	L	W	W	Y	S	S	N	W	P	N	R	Z	C

FALLEN PHRASES

	M	E	T	H	A	N	E	
	I	S		T	H	E		
		F	I	R	S	T		
M	E	M	B	E	R		O	F
			T	H	E			
A	L	K	A	N	E	S		

ALKENES

CRISS – CROSS PUZZLE



WORD SEARCH

I	O	P	L	N	J	M	E	G	G	M	G	A	D	E	C	H	V
C	S	Y	N	R	N	Z	L	Y	W	E	R	W	M	Y	H	Y	O
M	Z	O	O	F	X	O	E	Q	B	N	N	K	C	G	N	B	K
C	E	T	M	A	T	N	I	Z	H	S	Y	L	R	L	R	R	I
C	M	T	C	E	E	D	T	T	A	I	O	P	H	Y	D	I	N
S	R	X	F	K	R	X	W	A	A	A	Z	O	E	M	P	D	V
O	W	H	L	H	B	I	C	U	L	R	D	T	C	O	Y	I	O
E	R	A	X	M	L	I	S	K	Q	E	D	K	L	S	R	Z	K
T	H	N	H	M	P	P	E	M	T	L	N	Y	P	D	P	A	R
H	E	C	H	C	S	N	N	A	J	G	M	E	H	V	R	T	A
Y	D	O	H	T	E	M	R	E	Y	E	A	B	P	E	C	I	M
L	T	O	F	S	F	U	X	U	R	M	A	L	Y	O	D	O	P
E	V	M	S	Y	T	A	P	C	F	D	I	O	N	S	R	N	N
N	C	T	R	A	N	S	L	Y	N	E	K	L	A	X	T	P	O
E	S	B	S	L	E	A	L	K	A	D	I	E	N	E	S	U	L
O	C	N	C	W	D	P	U	F	V	Q	X	U	Y	J	X	N	F
S	U	D	I	P	P	E	X	X	W	A	Q	V	X	V	V	S	E
F	I	I	S	T	T	A	M	U	N	H	I	J	M	I	K	X	T

DOUBLE PUZZLE

YEROMPL	P O L Y M E R
MMNEROO	M O N O M E R
BUERRB	R U B B E R
RAUTUANSDET	U N S A T U R A T E D
BONIDP	P I B O N D
PEORENP	P R O P E N E
ATNIIDOD	A D D I T I O N
UZIACONNAVLIT	V U L C A N I Z A T I O N

Secret Message

DOUBLE

BOND

ALKYNES

WORD SEARCH

E	M	E	W	C	X	A	E	S	T	T	P	N	Y	S
U	T	N	T	R	X	N	H	U	A	E	Q	O	C	E
O	A	Y	Q	T	T	Y	M	R	Z	D	R	I	I	E
N	C	K	D	S	E	R	Z	U	E	R	X	T	N	B
V	Y	L	A	P	Y	P	K	T	P	L	Z	U	V	R
I	K	A	R	J	O	U	A	L	M	J	B	T	M	F
R	N	N	K	L	Q	R	E	E	U	S	N	I	O	O
A	O	V	Y	F	U	U	F	A	W	N	E	T	N	I
V	D	M	F	T	E	N	Y	T	N	E	P	S	O	K
R	E	D	A	C	E	T	Y	L	E	N	E	B	M	Y
R	E	S	I	K	G	W	Y	O	T	Y	G	U	E	G
D	N	M	P	T	B	Q	O	S	T	N	H	S	R	V
U	X	A	O	K	I	X	O	R	V	O	X	T	L	M
C	Q	P	Y	S	H	O	R	U	T	Z	F	O	O	P
U	V	X	H	S	I	G	N	E	B	V	Y	J	B	L

CRYPTOGRAM

CIS OR TRANS ISOMERISM IS NOT
POSSIBLE FOR ALKYNES BECAUSE
OF THEIR LINEAR GEOMETRY

AROMATICS

WORD SEARCH

E	J	Z	T	C	U	G	C	O	Z	A	S	B	B	F	B	X	J
M	N	H	B	Y	U	I	N	H	E	U	A	O	A	U	E	P	Y
U	A	E	O	E	T	X	E	I	B	E	T	A	J	F	N	Q	L
E	V	X	C	A	P	X	X	S	R	E	N	A	D	I	Z	V	X
H	T	C	M	A	A	T	T	V	Z	E	L	K	U	L	E	B	P
G	A	O	O	G	R	I	R	N	F	I	P	I	G	Z	N	M	T
F	R	F	O	R	T	H	R	A	L	O	P	N	O	N	E	O	D
A	P	N	F	U	G	U	T	N	X	E	J	E	D	E	L	P	C
X	A	N	T	S	I	P	K	N	H	A	L	N	I	U	B	D	S
L	A	I	L	I	X	O	Q	Q	A	P	U	Z	E	M	H	Z	T
V	O	W	U	X	Z	A	U	X	K	X	X	N	I	Y	T	F	Y
N	I	O	P	Y	L	L	O	M	Y	U	E	X	L	H	N	S	R
E	O	J	O	Q	L	G	O	B	K	V	N	I	D	H	S	L	E
N	A	P	H	T	H	A	L	E	N	E	Z	L	K	D	A	E	N
X	X	E	U	Z	C	O	B	F	N	D	D	W	A	O	B	T	E
P	K	D	S	I	O	X	A	B	U	D	A	C	P	F	L	A	N
P	H	E	N	O	L	S	K	Z	J	F	B	D	Z	H	G	K	A
A	R	E	N	E	B	Q	H	D	N	A	F	L	N	P	Y	A	U

FALLEN PHRASES

				T	H	E				
	S	I	M	P	L	E	S	T		
	A	R	O	M	A	T	I	C		
H	Y	D	R	O	C	A	R	B	O	N
I	S		B	E	N	Z	E	N	E	

INDEX

HYDROCARBONS

MODULAR SYSTEM

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